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NON-INDIGENOUS AQUATIC ORGANISMS IN THE COASTAL WATERS OF CALIFORNIA

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This study combined numerous field surveys with a literature review to document the location of non-indigenous aquatic species (NAS) in the estuarine and coastal waters of California. Substantial numbers of aquatic species have been introduced to the coast of California. Although all areas of the coast showed some evidence of introductions, NAS totals were generally highest in the two major commercial ports, San Francisco and Los Angeles/Long Beach. Statewide, 360 distinct non-indigenous and 247 distinct cryptogenic taxa were identified from the literature and field investigations during the course of this investigation. Annelids, primarily polychaete worms, were the dominant phylum, comprising 33% of the NAS observed. Eleven NAS were found in the current survey that had not been reported from California in previous studies. The majority of organisms introduced to the California coast are native to the northwest Atlantic, the northwest Pacific, and the northeast Atlantic, all regions from which California receives a considerable amount of ship traffic as well as the source materials for much of its aquaculture. Shipping is the most likely vector for the majority of NAS introductions; specifically, ballast water and hull fouling were identified as the most common subvectors. We identified a number of NAS that co-occur in the major ports, which may indicate intra-coastal spread of non-indigenous taxa. However, the mechanisms of NAS movement within California are poorly understood and should be addressed in future research.

INTRODUCTION

The introduction of non-indigenous aquatic species (NAS) has created serious ecological, operational, and engineering problems worldwide, including California. Non-indigenous animals and plants are commonly reported in many of the harbors and bays of California and have had a profound impact on the ecology of the marine and estuarine regions of California (Race 1982, Alpine and Cloern 1992, Cohen and Carlton 1995, Crooks 1998, Byers 2000, Grosholz et al. 2000). NAS may out-compete or alter local habitats to such an extent that they make it impossible for native species to survive, are often predators, competitors, or parasites and some can cause or carry disease (Lambert et al. 1992, Byers 2000, Grosholz et al. 2000, Ruiz et al. 2000). Through both direct and indirect mechanisms, NAS can pose risks to human health, devastate fishery and aquaculture resources, and severely disrupt habitat and ecosystem stability (Alpine and Cloern 1992, Ruiz et al. 2000, Purcell et al. 2001).

Although several human transport vectors have been implicated in the spread of NAS, commercial shipping is the dominant vector for coastal marine and estuarine introductions around the world and on the Pacific Coast (Cohen and Carlton 1995, Ruiz et al. 2000, Fofonoff et al. 2003, Hewitt et al. 2004, Drake et al. 2005). With the development of modern long-range ships in the 20th century, ballast water, used for ship stability, emerged as an important mechanism of dispersal of marine and freshwater organisms. Today, ballast water is considered the largest single vector for the transfer and release of NAS to locations outside their native range (Carlton and Geller 1993, Ruiz et al. 1997).

Ship ballast tanks typically contain numerous species in great abundance, which are subsequently discharged at ports of call (Carlton 1985, Carlton and Geller 1993, Smith et al. 1999). Worldwide, at least 10,000 marine species are estimated to be transported daily in the ballast water of cargo ships (Carlton 1999). Large vessels can carry in excess of 200,000 m^3 of ballast (National Research Council[1] 1996) and it is estimated that tens to hundreds of millions of live organisms may be discharged on any one voyage (Lavoie et al. 1999). Greater ballast tank volumes, increasing international commerce, and shorter transit times, have combined to increase the number and diversity of viable organisms potentially invading new habitats via shipping pathways and has contributed to the increasing rate of successful invasions (Cohen and Carlton 1998). Furthermore, as source ports become increasingly invaded, the diversity of exported species may expand and increase "stepping-stone" invasions, the process whereby an invaded location serves as a source for secondary introductions (Bagley and Geller 2000).

California's Ballast Water Management Act (Act) of 1999 established a multi-agency program to address the issue of species introductions by making ballast water management mandatory for all vessels entering California marine waters with ballast from foreign ports. The Act also provided funding for the present investigation, which entailed a biological assessment to determine the current location of non-indigenous aquatic species populations in the estuarine and coastal waters of the state. To gather this information, biological surveys were conducted in habitats where species introduced from ship's ballast would most likely occur. In addition, the Act anticipated that the data generated by this investigation would be used in future studies, such as the determination of alternative ballast water discharge zones, the delineation of environmentally sensitive areas to be avoided for uptake or discharge of ballast, and an assessment of potential risk zones where uptake must be prohibited. Data from this study will be used as a baseline to assess the effectiveness of ballast water control measures on species introductions into California.

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[1]National Research Council. 1996. Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ship's Ballast Water. Committee on Ships' Ballast Operations, Marine Board, Commission on Engineering and Technical Systems, U.S. Congress, Office of Technology Assessment, Harmful Non-Indigenous Species in the United States, OTA-F-565, Washington, DC.

METHODS

Data Collection

Data used in this investigation were derived from field collections directed by the California Department of Fish and Game's (CDFG) Office of Spill Prevention and Response, from comparable concurrent studies being conducted independently by other organizations, and from a comprehensive literature review. Data collection focused on suspected NAS and cryptogenic taxa only; data on native taxa were not used in this investigation, except in cases of known range extensions.

Primary Studies

The CDFG field studies focused on those areas of the coast that had not been surveyed specifically for NAS in past investigations, specifically targeting regions most likely to be impacted by ballast introductions. The study initially targeted the seven major ports along the California coast: Humboldt Bay, San Francisco Bay, Stockton, Sacramento, Port Hueneme, Los Angeles/Long Beach (LA/LB), and San Diego (Figure 1). These sites are the primary locations where ocean-going vessels enter state waters, thus were the most likely places for ballast-related introductions to occur. NAS were sampled and identified in all these port areas except San Francisco Bay, which had already been extensively studied in recent years, most notably by Cohen and Carlton (1995), whose data is included in our summaries. Most of the sampling in the major port areas was conducted in 2000. Subsequent to the survey of the major ports, additional sampling was done in many of the smaller marinas and bays along the coast during the summer of 2001 (Figure 1).

CDFG contracted with three scientific research groups to assist with sample collection and literature review. With minor overlap, each group was responsible for collection and identification of organisms in different geographic areas: Moss Landing Marine Laboratories' Marine Pollution Studies Lab (MLML) sampled harbors, marinas, and bays statewide; Humboldt State University Foundation (HSUF) sampled Humboldt Bay; and San Francisco Estuary Institute (SFEI) sampled the major ports of southern California. All began their research with a comprehensive literature review of non-indigenous organisms in the marine and estuarine waters of their respective study areas. The literature review was based on both published and unpublished information, including scientific papers, graduate theses, government reports, regional monographic studies, keys, floras, field guides, check lists, as well as museum and personal collections and records. Sampling encompassed a variety of habitats, methods, and locations (Table 1).

The majority of the sampling for this survey was done by MLML and was designed to supplement existing information and data being collected by other researchers. Samples were collected at over 450 stations in 21 harbors, marinas, and bays; epifaunal samples were taken in all locations, infaunal communities were sampled in 4 harbors, zooplankton were identified from samples taken in Humboldt Bay, Port Hueneme, LA/

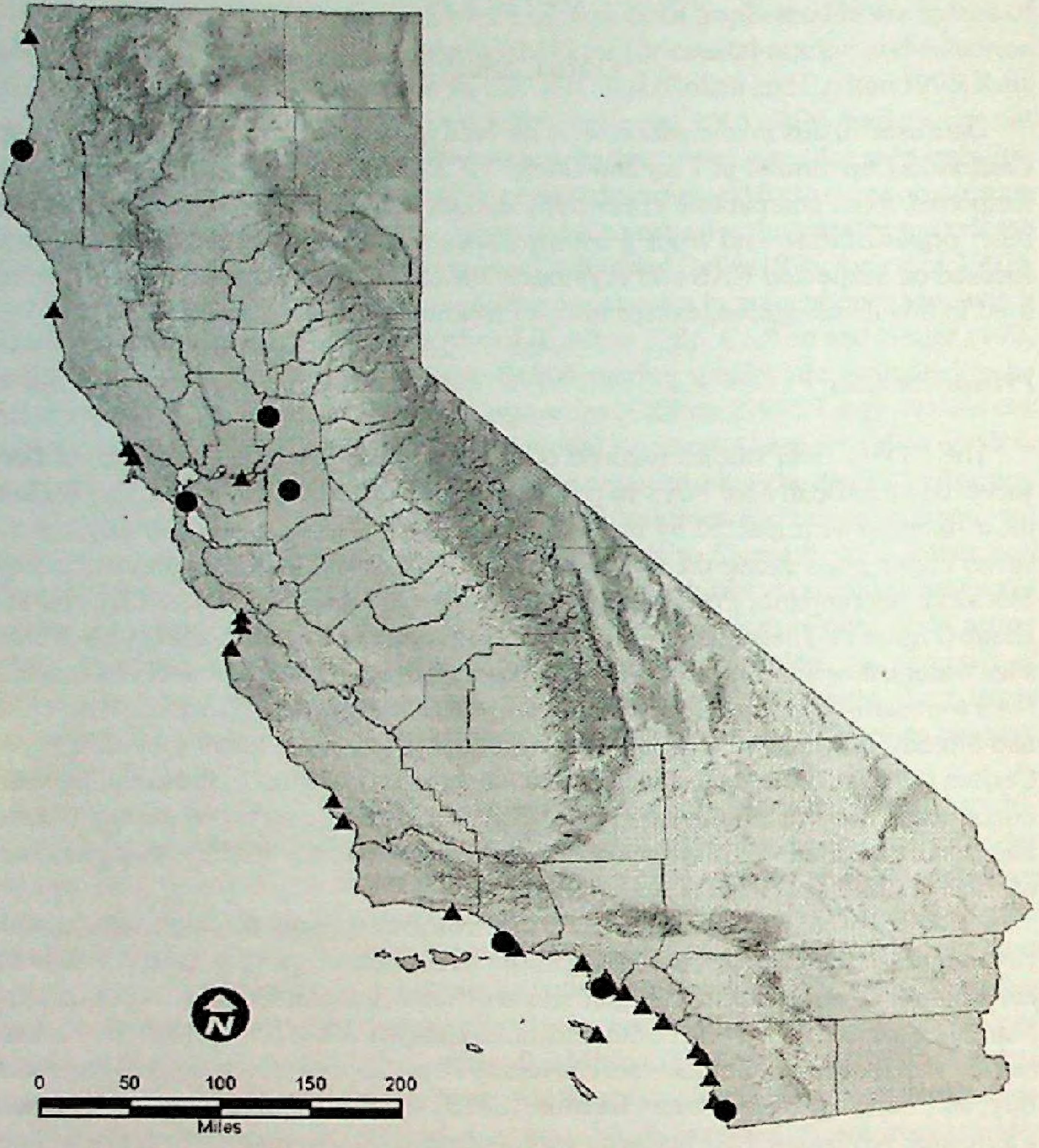

Figure 1. California major harbors and minor bays and ports sampled for non-indigenous taxa.

LB Harbor and San Diego Bay, and fish surveys were conducted in the ports of Sacramento and Stockton (CDFG[2] 2002). Benthic infaunal samples (sediment grabs) were collected at 77 stations in 4 harbors. Zooplankton samples were collected quarterly in San Diego Bay, LA/LB Harbors, and Port Hueneme. Voucher specimens of all identified NAS and cryptogenic taxa were maintained by MLML.

[2]California Department of Fish and Game (CDFG). 2002. A Survey of Non-Indigenous Species in the Coastal and Estuarine Waters of California. California Department of Fish and Game. Sacramento, California. Report to the California State Legislature. pp116.

Table 1. Types of sampling conducted at key coastal California sites. Includes field sampling conducted between 1998 and 2001 by Moss Landing Marine Laboratories, Humboldt State University Foundation, San Francisco Estuary Institute, and the Southern California Coastal Water Research Project Authority.

Water Body	Epifaunal	Benthic	Fish	Plankton	Algae	Fouling Plate
Humboldt Bay	X	X	X	X	X	X
Port Hueneme	X	X	X	X		
Port of Sacramento	X	X	X			
Port Of Stockton	X	X	X			
LA/LB Harbors	X	X	X	X		
San Diego Harbor	X	X		X		
Fort Bragg	X					
Tomales Bay	X	X				
Bodega Bay	X					
Elkhorn Slough	X					
Moss Landing Harbor	X					
Monterey Harbor	X					
Morro Bay	X					
Santa Barbara	X					
Channel Islands Harbor	X	X				
Marina Del Rey	X	X				
Huntington Harbor	X	X				
Anaheim Bay	X	X				
Newport Harbor	X	X				
Dana Point	X	X				
Oceanside	X	X				
Agua Hedionda Lagoon	X					
Mission Bay	X	X				
Avalon Harbor	X					

MLML sampling protocols were designed to maximize the probability that NAS would be detected by directing effort to locations and habitats most likely to have been colonized by these organisms. Sampling focused on areas within harbors and bays that had a high potential for ballast water release, on calm backwaters where species could collect and flourish, on recently established docks which could provide a comparison to growth on older docks, and on habitats at harbor entrances. Within these general areas, priority was given to active and inactive shipping berths, fishing vessel docks, recreational marinas, aquaculture facilities, and newly constructed structures. Sample sites were spread throughout each port, harbor, or bay to give spatial representation and to accommodate differences in tidal flushing and mixing. Because habitat differences can influence larval recruitment and subsequent colonization, the sampling strategy also encompassed multiple depths, substrates, and light exposure conditions.

The HSUF conducted sampling in Humboldt Bay, focusing on the fish, benthic, and fouling communities. Beginning in July 2000, HSUF researchers collected benthic

samples at 87 sites, epifaunal samples at 21 intertidal and 5 marina locations, and fish samples at over 300 locations throughout the Bay. Samples were collected during the mid- to late summer to minimize the collection of large numbers of juvenile specimens which occur in the spring months and are often difficult to identify. Sampling for algae occurred at 58 sites with hard substrata where green, red, and brown algae might grow. Several soft-bottom sites were selected as potential locations where the flowering plant *Zostera japonica*, a suspected invader in the Bay, could thrive. In addition, settling plates, made of standardized PVC panels (National Research Council[1] 1996), were used to collect fouling organisms. All specimens were sorted and identified in the laboratory by taxonomic specialists with expertise in the marine invertebrate species of Humboldt Bay, as well as the benthic species of the Bay and adjacent outer coast. HSUF sampling in Humboldt Bay was supplemented by collection of zooplankton samples by CDFG on a quarterly basis over the course of one year beginning in spring 2001.

SFEI conducted a Rapid Assessment Survey in Southern California, focusing primarily on the fouling community in selected sheltered waters from San Diego to Oxnard, with sampling sites chosen to represent conditions in the three major port areas of the region, San Diego, LA/LB, and Port Hueneme (Cohen et al. 2005). The Rapid Assessment Surveys were intended to supplement other sampling surveys in these areas. A team of taxonomic experts was assembled to conduct the sampling and identification of organisms at 22 sites in the study area. Samples were collected primarily from the fouling community on docks and pilings, with some additional samples from the adjacent soft benthos, nearby intertidal and selected subtidal habitats. Specimens were identified in the field followed by confirmation in the laboratory by the expedition team, as well as taxonomic specialists at the Los Angeles County Museum of Natural History and the San Diego Ocean Monitoring Laboratory.

Supplemental Studies

To maximize the resources available to collect data and complete the picture of NAS invasions along the California coast we incorporated the results of three other recent or concurrent surveys: the Los Angeles/Long Beach Baseline Study, the Southern California Bight 1998 Regional Marine Monitoring Survey (Bight 98), and the U.S. Environmental Protection Agency's Western Environmental Monitoring and Assessment Program (WEMAP).

The Los Angeles/Long Beach Baseline Study was an environmental study conducted in the ports of Long Beach and Los Angeles in 2000, which was intended to establish a baseline for the benthic invertebrate community and the larval, juvenile, and adult fish populations, and to update knowledge of the fouling communities attached to rocky rip-rap habitats (MEC[3] 2002). The Southern California Coastal Water Research Project Authority (SCCWRP) embarked on a project to assess the nature and

[3]MEC Analytical Systems, Inc. Ports of Long Beach and Los Angeles Year 2000 Baseline Study. ORTEP Association, "Pathways of Introduction and the Ecological and Economic Impacts of Invasive Species", http://www.ortepa.org/pages/ei26.htm , accessed May 2002.

relative magnitude of seasonal and climatic variation in benthic invertebrate populations as part of the Bight 98 Survey (Ranasinghe et al. 2005). Coastal WEMAP was a regional program to collect coastal and estuarine infaunal samples from California, Oregon, and Washington during 1999 (US EPA[4] 2001).

Introduction Status, Vectors, and Origin

We categorized the introduction status of taxa as non-indigenous, cryptogenic, or "nativeX". Non-indigenous species are those plants and animals that are living outside their natural geographic boundaries. Cryptogenic taxa are those that are neither demonstrably native or introduced (Cohen and Carlton 1995, Carlton 1996). These taxa have been identified but their native range or region is unknown. In some cases, taxa could not be resolved to species level, so were conservatively assigned "cryptogenic" or "unknown" introduction status. For these unresolved taxa, introduction status was determined on a case-by-case basis. In some instances, if we were confident that all the species from a particular genus were non-indigenous to California, we assumed that any species from that genus found in California was introduced. The introduction status of each taxon was based on documented research and personal communication with taxonomic experts. NativeX is a term that describes species that have been classified as native to California, but were found outside their previously known geographic range. The nativeX designation connotes a possible range extension for these species, which may or may not have been facilitated by human action.

We labeled taxa that could not be identified unambiguously as "non-distinct" and used the term "distinct" to indicate taxa that unambiguously represent a unique taxon. Many genera identified in the study have at least one species that is indigenous to California. Thus, it was often unclear whether an organism identified as "*Genus sp.*" represents a unique (distinct) species and/or whether that species is native or introduced. Unless otherwise noted, we have reported only "distinct" taxa in the summary figures, which results in a somewhat conservative listing of introduced and cryptogenic species, but avoids the problems associated with counting a genus as a distinct taxon when it may not be.

Many of the species included were collected from more than one site within the specified harbor areas but, unless otherwise noted, were counted only once in the summaries. However, all summaries of introduction vectors include species in more than one category if the literature indicated that they were polyvectic (having multiple potential vectors). Non-distinct taxa and cryptogenic taxa were not included in vector summaries.

The regions of origin of NAS were classified into eight major oceanic quadrants: northeast Atlantic, northwest Atlantic, southwest Atlantic, northeast Pacific, northwest

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[4]U.S. EPA. 2001. National Coastal Assessment: Field Operations Manual. U. S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. EPA 620/R-01/003. pp72.

Pacific, southwest Pacific, and Indian Ocean. Some records from the literature regarding the nation or region of origin for NAS were either speculative or very general. Some data sources listed very generic possible origins, such as "Atlantic" or "Asia" or listed a number of potential native ranges that spanned most of the globe (so-called "cosmopolitan" species). Such species were included in each of the regions of possible origin identified in the literature.

RESULTS

State-Wide Totals

A total of 352 distinct non-indigenous taxa was identified from the literature and field surveys during the course of this investigation. In addition to these introductions, 393 other taxa were either of uncertain origin (cryptogenic, 246), represented range extensions within California (nativeX, 11), or could not be identified to the required taxonomic level (non-distinct, 136) (Figure 2).

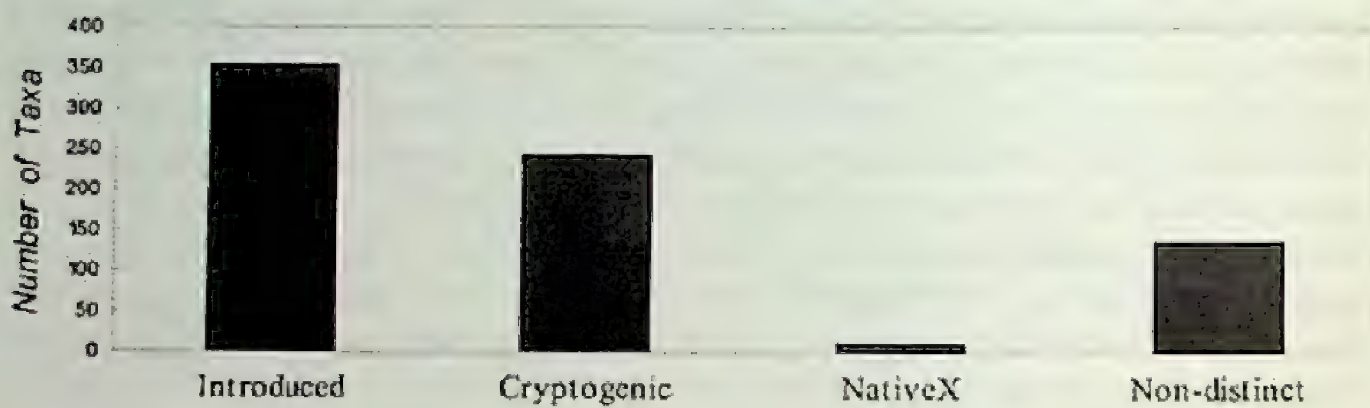

Figure 2. Numbers of non-indigenous taxa in coastal California waters by introduction status category.

Distinct non-indigenous taxa represented 24 phyla, but 4 phyla accounted for greater than 75% of non-indigenous taxa: Annelida, Arthropoda, Chordata, and Mollusca (Figure 3). Annelids, primarily polychaete worms, were the dominant phylum, comprising 33% of the non-indigenous taxa identified (52 introduced and 147 cryptogenic). Arthropods were the second most abundant phylum identified, comprising 22% of non-indigenous taxa (89 introduced and 41 cryptogenic). Amphipods were the most common group of arthropods identified. Chordates (primarily fish and tunicates) accounted for 13% of non-indigenous taxa and molluscs made up 10% of the total. Although most non-indigenous organisms were found in marine habitats, the vast majority of the fish species identified were from fresh and brackish water habitats, including the Sacramento-San Joaquin Delta and the location of two primary study sites, the ports of Sacramento and Stockton.

Eleven new NAS were identified in this study that had not been found in previous

Figure 3. Non-indigenous taxa in coastal California waters by phyla.

studies. In Humboldt Bay, newly found taxa included three polychaetes, *Boccardiella hamata, Euchone limnicola,* and *Fabricia sabella*, an amphipod, *Incisocalliope nipponennis,* and the eelgrass, *Zostera japonica. Alderia modesta*, a gastropod, was observed in northern California. Newly observed taxa in southern California included the amphipod, *Phtisica marina,* in Port Hueneme; the isopod, *Munnogonium wilsoni*, in LA/LB Harbor; the isopod, *Pleurocope floridensis,* in Avalon Harbor; the green alga, *Caulerpa taxifolia*, in San Diego County; and the branchiopod, *Eulimnadia texana*, along the coast.

Across all locations, shipping was the most common probable introduction mechanism for NAS, with ballast water and hull fouling being the most common probable subvectors (Figure 4). The majority of the species introduced to California appear to be native to the northwest Atlantic, the northwest Pacific, and the northeast Atlantic (Figure 5).

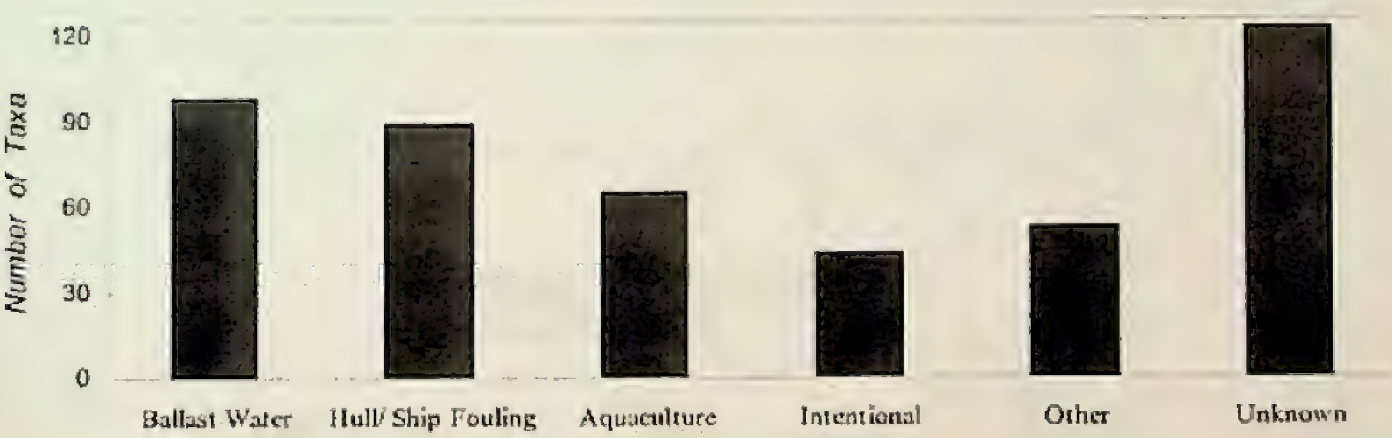

Figure 4. Introduced species in coastal California waters by vector. "Other" includes aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast. Only "distinct taxa" are included. Species with multiple potential vectors have been counted in more than one category.

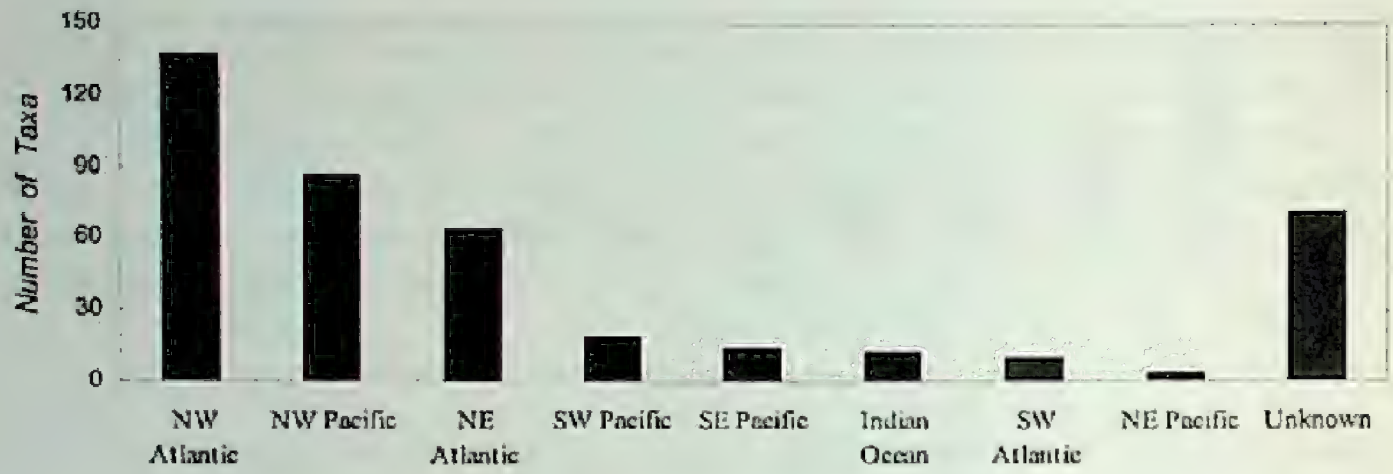

Figure 5. Non-indigenous species in coastal California waters by region of likely origin.

Major Harbor Areas

All the major harbor areas in California have received significant NAS introductions (Figure 6). Each major commercial harbor area of the state had between 50 and nearly 250 species that are either clearly non-indigenous or considered to be very likely non-indigenous. San Francisco Bay had the greatest number of NAS, but the other major port, LA/LB, had only slightly fewer NAS. The major harbor areas had a number of NAS in common; San Diego Bay and LA/LB Harbor shared 40 NAS, and 59 NAS that occur in San Francisco Bay also occur in Humboldt Bay. However, quantitative comparisons among ports or bays are difficult because sampling methods, seasons, and effort varied considerably among the different studies.

The primary introduction pathways differed somewhat for each of the major harbor areas (Figure 7) and the number of "unknown" vectors was substantial. The combination of ballast discharges and hull fouling were the primary potential mechanisms of introduction in all areas except the freshwater ports of Sacramento and Stockton (Inland Ports). Intentional introduction, primarily of fish species, was the leading probable vector in the Inland Ports and in the Delta. Hull fouling was the most common introduction probable vector in four harbors, Humboldt Bay, Port Hueneme, LA/LB,

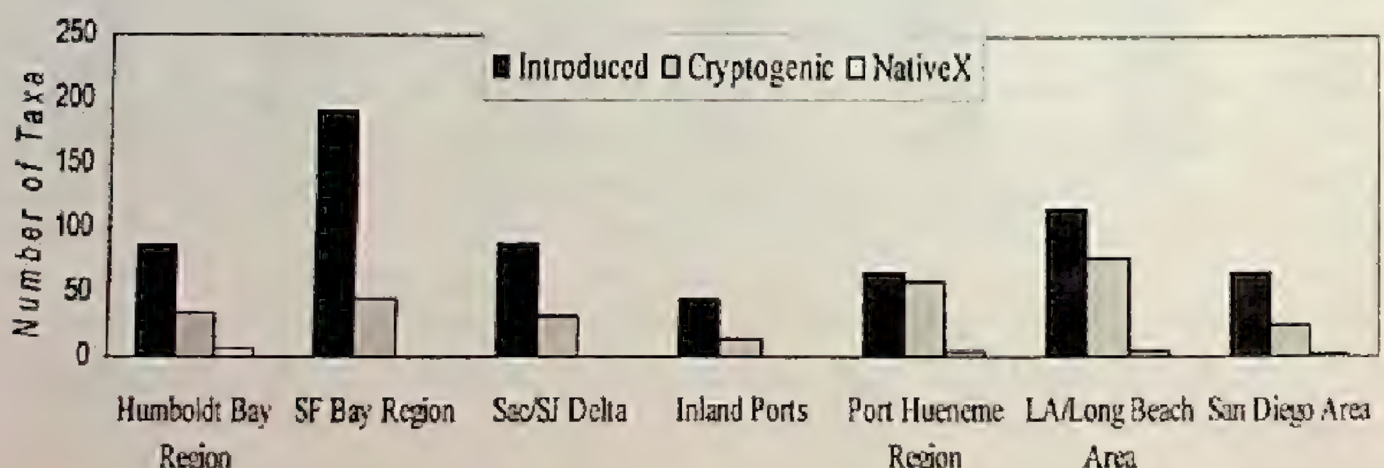

Figure 6. Non-indigenous species in major harbor areas of California.

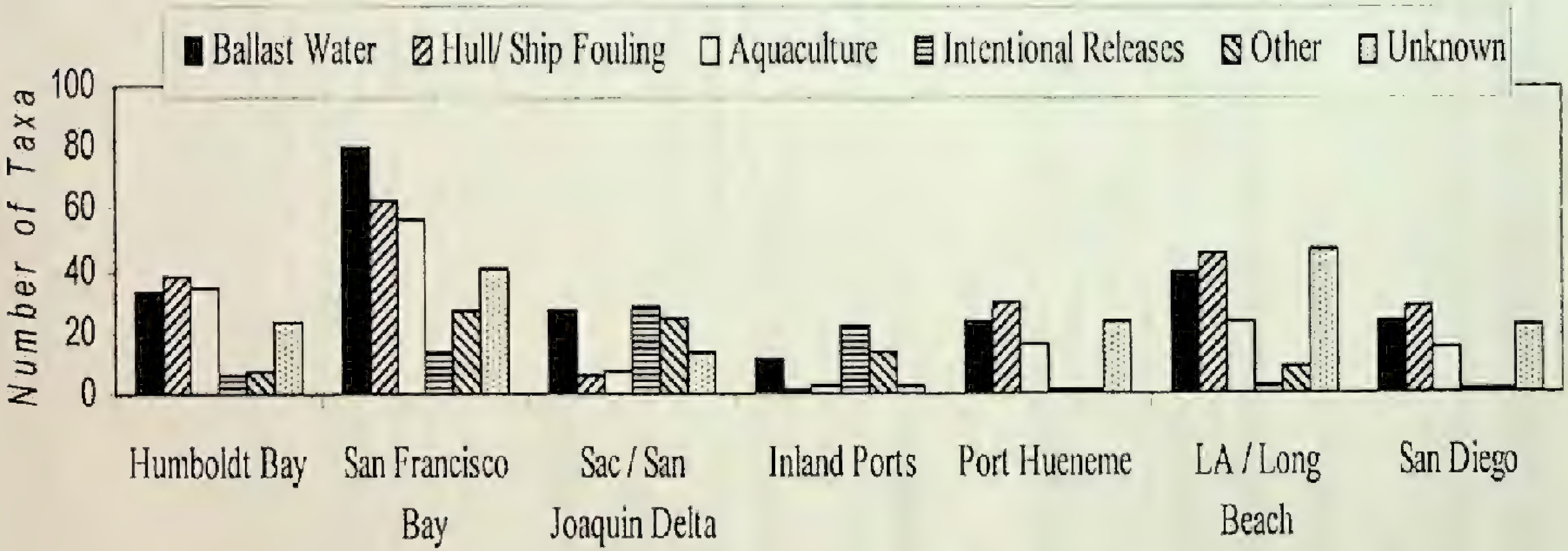

Figure 7. Primary introduction vectors in major harbor areas of California. "Other" includes aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast. Only "distinct taxa" are included. Species with multiple potential vectors have been counted in more than one category.

and San Diego. Ballast water was the next most common probable vector in these regions but was not the dominant probable vector in any area except San Francisco. Aquaculture was the second most common probable vector in Humboldt Bay and the third most important source of introductions in San Francisco, Port Hueneme, LA/LB, and San Diego.

Minor Harbors

Substantial numbers of non-indigenous taxa were also found in the smaller ports and bays. Over 70 non-indigenous taxa were identified in Tomales Bay (Figure 8). Morro Bay, Bodega Bay, and Oceanside Harbor also contain high numbers of NAS.

As with the major harbors, the shipping vectors, particularly hull fouling, appear to be the primary means of introducing new species to smaller ports. Hull fouling is the leading probable vector in eight of the selected harbors and the second leading probable vector in the remaining four areas presented (Figure 9).

DISCUSSION

This study confirms that there have been a substantial number of aquatic species introduced to coastal ecosystems of California and that all areas sampled showed some evidence of introductions. NAS totals were generally highest in the two major commercial ports, San Francisco and LA/LB. These ports receive the largest amount of ship traffic and therefore have the greatest exposure to vessel-related pathways of introduction. However, the smaller commercial ports (Humboldt Bay, the Sacramento/San Joaquin Delta, the Inland Ports, Port Hueneme and San Diego) and the many small harbors, bays, and estuaries along the coast also have a substantial number of NAS.

Different methods among the major harbor areas impaired our ability to make meaningful quantitative comparisons. For example, while our data suggest that San Francisco Bay continues to be, as once described, one of the most invaded ecosystems in California, if not the world (Carlton and Cohen 1995), this conclusion may be biased by the extensive monitoring effort in this region. Drake and Lodge (2003) speculated that this reflects a greater investment of research in San Francisco Bay and that NAS in other areas may persist undetected because of a lack of search effort. They demonstrated that the San Francisco Bay and Delta, although known to have a large number of NAS (Cohen and Carlton 1998), is of relatively minor importance as a source of introduced species for other ports. Contrary to this conclusion, however, our study shows that San Francisco Bay and Humboldt Bay have a high number of NAS in common, indicating a high likelihood of cross-inoculation between California embayments. Ongoing CDFG studies should help evaluate this potential source of bias.

Vectors

Data from this study suggest that shipping is the main probable vector responsible for introductions of aquatic species in California. Ruiz and others (2000) found that

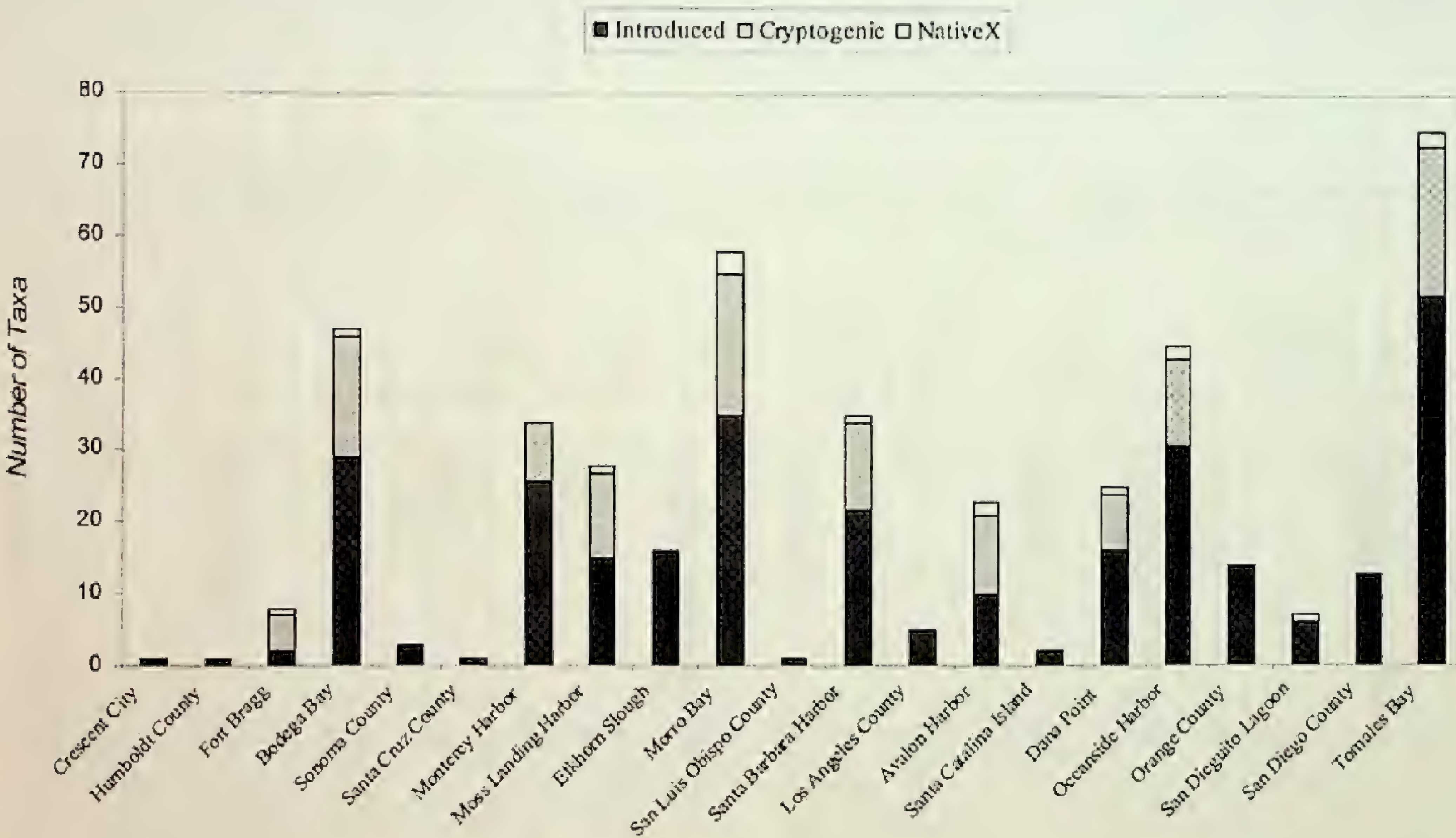

Figure 8. Non-indigenous species in minor ports and bays in California.

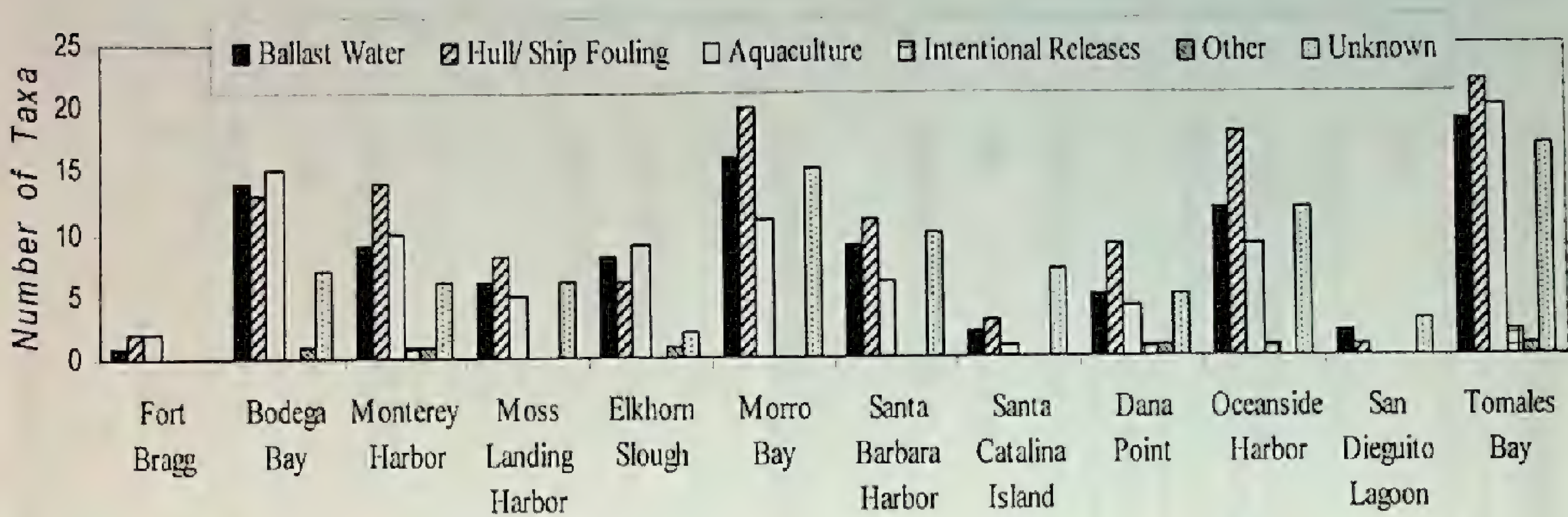

Figure 9. Primary introduction vectors in selected ports and bays of California. "Other" includes aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast. Only "distinct taxa" are included. Species with multiple potential vectors have been counted in more than one category.

shipping was the sole vector for 51% of initial North American invasions and 59% of the repeat invasions. Discussion of introduction vectors is complicated by the fact that many taxa are polyvectic (Carlton and Ruiz 2005). A further complexity is that the relative contribution of the ballast water and hull fouling subvectors is extremely difficult, if not impossible to distinguish (Fofonoff et al. 2003). The field collections in our study specifically targeted areas likely to receive ballast water and, thus, may be over-estimating the importance of the shipping vector statewide. Despite these concerns, it is obvious that shipping traffic plays a significant role in dispersal of new species into California waters through a combination of ballast discharges and hull fouling.

Hull fouling, which is a dominant source of introductions in many harbors, appears to have had less of an impact in the Sacramento/San Joaquin Delta and Inland Ports. It is likely that low salinity is a limiting factor for marine fouling organisms, acting as a barrier to survival. Freshwater exposure has been used as an effective means of eliminating marine fouling organisms from ship's hulls (Brock et al. 1999).

It also appears that hull fouling may play an even more important role in the smaller harbors than in the larger ports. Wasson et al. (2001) found that 70% of NAS in Elkhorn Slough were associated with hull fouling. They noted that many resident fishing and pleasure boats frequently travel up and down the coast from port to port and that there is also an annual migration of fishing boats along the California coast, providing ample opportunity to deliver NAS to such small estuaries. However, our study disproportionately sampled fouling communities in the smaller harbors, which may have resulted in an over-estimation of the role of ship fouling.

Although many of the introductions have come by ship, aquaculture and intentional introductions (primarily of fish) were the probable vector for most of the NAS observed in freshwater and euryhaline habitats. Excluding anadromous species, no successful introductions of fish have been made to the marine waters of California (Dill and Cordone 1997). It appears that aquaculture has the same or an even greater influence than ballast water discharges outside the major harbor areas.

A substantial number of taxa had unknown vectors of introduction (~28%). It is often difficult, and in many cases impossible, to determine the mechanism of transport with even a moderate degree of certainty. Further study could reduce the unknown element of this question. Tracing invasion history using molecular techniques is one such area of research that may elucidate mechanisms of introductions.

Although this study has established some of the probable vectors of initial introduction of NAS to California from foreign ports, the mechanisms of NAS movement within California are poorly understood. Whether NAS are introduced directly to smaller bays and estuaries or spread secondarily from the larger ports is also not well understood. Initial introductions from ballast, hull fouling, or aquaculture may be exacerbated by fishing or recreational boats that move between the large harbors and smaller bays. Intra-coastal shipping may also play a key role in the spread of NAS between major ports. In this investigation, we identified a number of NAS that co-occur in the major ports, which may indicate intracoastal spread of non-indigenous taxa. Since survivorship of organisms in ballast water declines with increasing voyage duration, short domestic voyages have the potential to transfer greater abundances of organisms

than longer foreign voyages (Lavoie et al. 1999). Transit time for ships between California ports can be measured in hours, enabling rapid spread of NAS along the coastline via ship traffic. The control of already established NAS populations can only be accomplished if we are able to prevent the spread to nearby ports, bays, and estuaries. Further research is needed to refine our understanding of the extent of secondary or tertiary introductions and spread of NAS both along the Northeast Pacific coast and within California.

Origins

The majority of the species introduced to California appear to have come from the northwest Atlantic, the northwest Pacific, and the northeast Atlantic. These are also the regions of the world from which California receives a considerable amount of ship traffic as well as the source materials for much of its aquaculture. Ruiz and others (2000) also found that most marine invasions to the West Coast originated from the Indo-West Pacific (including Western Pacific) and Western Atlantic and that introduction routes corresponded directly to the dominant trade corridors in historical time. Although native range information can tell us where species originate, it cannot tell us if they came to California directly from their native region or from some intermediate location. To make this determination, information on source region (the probable area from which an introduction occurred) is needed and should be included in future studies.

Sampling Limitations

This survey provides a sound baseline for future research to examine the impact that non-indigenous animals and plants may have on the health of the aquatic environment of California's coast, but these summaries undoubtedly underestimate the true number of NAS in California because of sampling limitations that included seasonal effects, under-representation of certain habitats, and under-representation of small organisms.

The seasonal timing of sampling created the possibility that some non-indigenous taxa were not observed. Settling plates used in Humboldt Bay revealed that there are many fouling community species that establish themselves in the spring and disappear by mid to late summer; thus it is possible that due to our sampling design we may have missed some NAS whose ease of collection varies seasonally.

Although efforts were made to sample a broad range of habitats in the many areas studied, limited time and resources caused sampling in the minor ports, bays, and marinas to focus primarily on the fouling community. Since it was not possible to sample all subtidal and intertidal habitats or include all communities in the study design, the sampling effort may have under-represented the full NAS impact in some areas. Two habitats, the crevices within the rocks and rip-rap of break-waters and the hard bottom benthic substrate were not sampled successfully in this study. Attempts were made to trap fish in the rocky crevices, but no specimens were caught. The hard bottom substrate was sampled in the LA/LB Harbors but there were insufficient resources to

sample this habitat in other areas of the state. As this habitat typically supports a diverse community, efforts should be made to collect samples from these areas in any future research.

We focused our sampling of the plankton community on zooplankton, to the exclusion of phytoplankton. As the phytoplankton community is easily transported by ballast water, there is a potential for introduced phytoplankton species occurring in our bays and estuaries. Phytoplankton species are the cause of some of the detrimental blooms along the east coast of the United States which have resulted in major fish kills. This community should be studied in future investigations.

Finally, there is a general pattern that smaller organisms tend to be under-sampled and the quality of systematic and biogeographic information diminishes with organism size (Ruiz et al. 2000). Therefore, the available baseline information for small organisms and microorganisms is poor relative to large invertebrates and vertebrates.

Ongoing Studies

Continued monitoring of California coastal waters is essential for determining if the rate of new introductions is changing and whether recent ballast water regulations have been successful in limiting introductions of new organisms. Also, while we did not measure relative abundance or the proportion of native to non-native taxa in this study, future monitoring will include relative abundance data, which will be used to determine the extent of impact that introduced organisms are having on the native biota and coastal ecosystems and should give us a better basis for determining the relative risk that NAS may pose should they spread to other areas of the state. Planned or ongoing monitoring for NAS in California includes re-sampling the harbors and ports, sampling along California's outer coast, and a survey of San Francisco Bay. As biological invasions of marine and estuarine habitats are increasingly studied, knowledge of the natural histories of non-native species will be vital to understanding and predicting new invasions. The present investigation should advance our knowledge of invasion vectors, sources, and impacts.

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HISTORIC ACCOUNTS, RECENT ABUNDANCE, AND CURRENT DISTRIBUTION OF THREATENED CHINOOK SALMON IN THE RUSSIAN RIVER, CALIFORNIA

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ABSTRACT

Despite their threatened status, little was known about the abundance and distribution of Chinook salmon in the Russian River, California, prior to 1999. Recent reviews considered the population extirpated or scarce and the existence of a historic population was questioned. To inform recovery planning efforts, we reviewed historic fishery documents and investigated the current status of Chinook salmon in the Russian River. We counted migrating adults at a seasonal dam using an underwater video system, determined redd distribution along mainstem and tributary habitats, and trapped emigrating juveniles in the lower river from 2000 to 2004. Minimum annual escapement ranged from 1,383 to 6,081 fish, one-time annual surveys found 558 to 1,044 redds throughout 110 km of the mainstem and more than 250 redds along 22 km of a major tributary, spawning was evident in an additional four tributaries, and we estimated that at least 20,021 to 225,135 juveniles emigrated annually. In contrast to previously published accounts, our 5-year monitoring results documented a relatively abundant, widely distributed, and naturally self-sustaining population. Recent genetic analyses and similarities between our data and historic information dating to 1881 suggest the presence of an ancestral population. However, the extensive planting of juveniles artificially propagated from out-of-basin stock and the paucity of historic field surveys makes the origin and demographic trends of the current population impossible to determine.

INTRODUCTION

Accurate descriptions of historic and current trends in abundance and distribution are fundamental components of threatened species recovery planning. The California Coast Chinook Salmon Evolutionarily Significant Unit (ESU) was listed as threatened in 1999 (U.S. Federal Register 64FR50394, September 16, 1999). The Russian River watershed comprises 18% of the ESU and forms the southern boundary. At the time of listing, however, information regarding the current status of Chinook salmon in the ESU was unavailable and historical accounts of their abundance and distribution were scarce (Myers et al. 1998). The paucity of information on Russian River Chinook

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salmon, *Oncorhynchus tshawytscha*, has led researchers to conclude that they were a minor component of the historical fishery and may have persisted only as a small population throughout the twentieth century (Winzler and Kelly 1978[1]; Steiner 1996[2]; Moyle 2002).

The origin and historic abundance of Russian River Chinook salmon is enigmatic. There is no information on their presence or absence prior to the first stocking in 1881 (USCFF 1892). Fish were stocked sporadically during the early twentieth century and a more concerted effort to establish a spawning population began in the 1950s and 1960s (Steiner 1996[2]; Myers et al. 1998). These stockings resulted in a minor fishery, but natural reproduction may have been unsuccessful (Jensen 1973[3]). After the construction of Warm Springs Dam and Lake Sonoma in the 1980s, the California Department of Fish and Game (CDFG) began propagating Chinook salmon using local and out-of-basin stock at the Don Clausen Fish Hatchery located on Dry Creek, a major Russian River tributary. More than 2 million juvenile salmon were released from the hatchery between 1981 and 1998 (Myers et al. 1998). Adult returns, however, ranged between 1 and 304 fish and the Chinook salmon hatchery program was terminated in 1999.

In 1999, the Sonoma County Water Agency conducted a pilot study to assess the effects of a seasonal dam and water diversion facility on Russian River fisheries (Chase et al. 2000[4]). Although designed primarily to evaluate the upstream and downstream passage of threatened coho salmon, *O. kisutch*, and steelhead, *O. mykiss*, Chinook salmon were encountered most frequently. The extension of the pilot study to a 5-year fish passage investigation (Chase et al. 2005[5]; Manning et al. 2005) has revealed the presence of a previously poorly described Russian River Chinook salmon population.

To clarify the historical record and facilitate California Coast Chinook salmon recovery planning efforts, we provide (1) a comprehensive review of historic Russian River fishery documents, (2) the number and timing of returning adults for the years 2000-2004, (3) the distribution of redds in mainstem and tributary habitats from 2002 to 2004, and (4) the number and timing of emigrating juveniles for the years 2000-2004.

Study Site

The Russian River drains a 3,846-km^2 watershed in Mendocino and Sonoma counties. The 177- km mainstem river enters the Pacific Ocean 112 km north of San Francisco, CA (Fig. 1). Stream flow is currently regulated by releases from two permanent reservoirs: Lakes Sonoma and Mendocino. Both reservoirs are located on tributaries and provide summer base flows of 6-9 m^3/s, but winter discharge is largely unregulated. Historic unimpaired summer flows were generally less than 0.57 m^3/s. The Sonoma County Water Agency withdraws water to meet municipal demands at river km (rkm) 37 (above the river mouth) near the town of Forestville (Fig. 1). During the low flow season (April-November) a temporary dam and reservoir is used to enhance groundwater pumping. Mirabel Dam, a 45-m x 4.0-m air and water-filled rubber bladder creates a 5.1-km reservoir termed Wohler Pool. To facilitate upstream fish passage and minimize juvenile entrainment, the dam contains two Denil-style fishways and screened pump intakes with flow bypasses (Manning et al. 2005). Water not diverted through

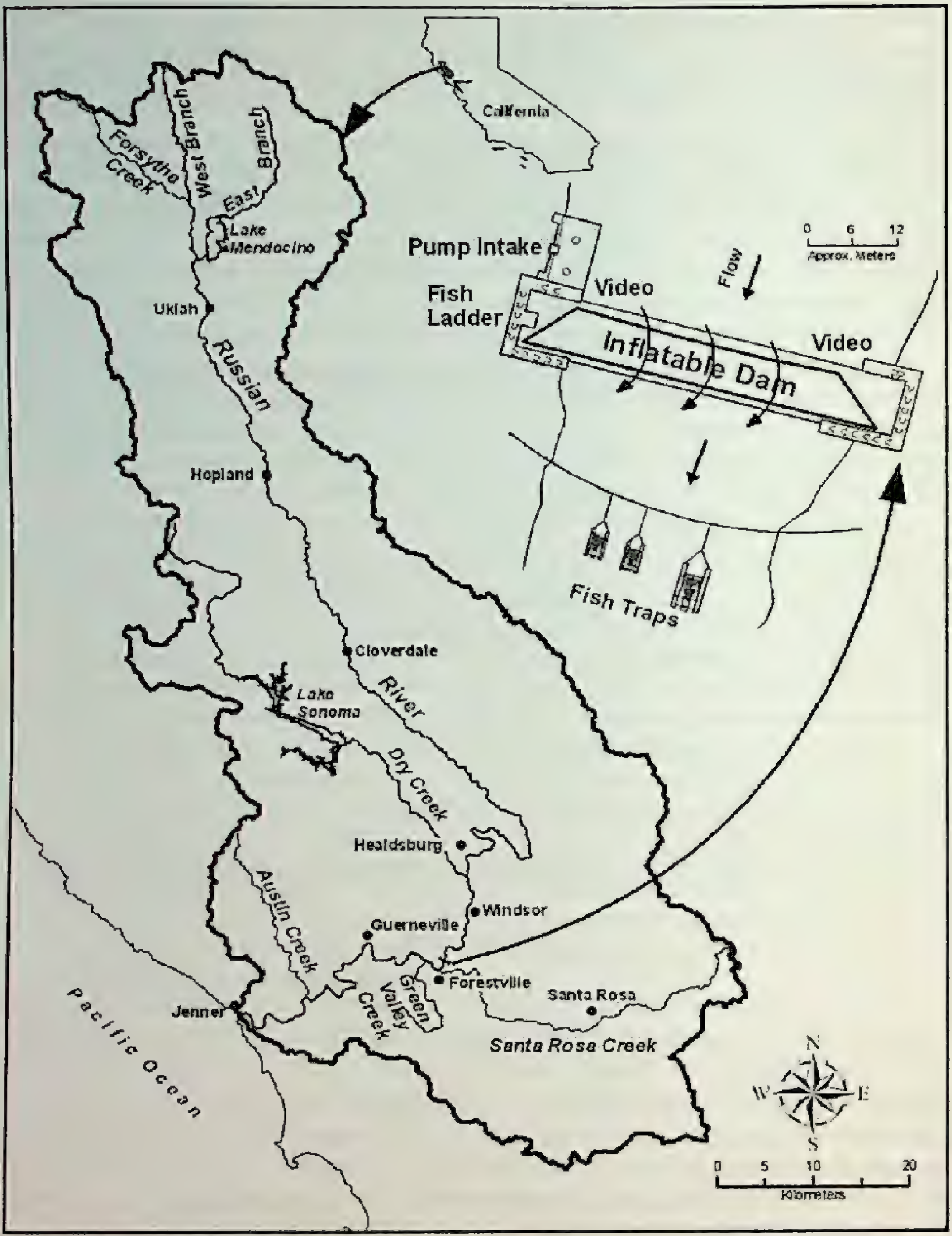

Figure 1. The Russian River watershed Chinook salmon study area showing major spawning tributaries and detail of the Mirabel inflatable rubber dam sampling site. Underwater video cameras were located at the fish ladder exits on the upstream side of the dam. Rotary screw fish traps captured emigrating juveniles below the dam site.

the intakes, bypasses, or ladders spills evenly across the crest of the structure. During periods of non-operation, the dam is deflated and lies flush with the streambed.

The Russian River provides habitat for Federal Endangered Species Act (ESA) threatened Chinook salmon, steelhead, and State and Federal ESA endangered coho salmon. In addition to salmonids, smallmouth bass, *Micropterus dolomieu*, Sacramento sucker, *Catostomus occidentalis*, pikeminnow, *Ptychocheilus grandis*, hardhead, *Mylopharodon conocephalus*, and tule perch, *Hysterocarpus traski*, are abundant in the river (Chase et al. 2005[5]).

METHODS

Document Review

Our search for historic Russian River fishery documents was conducted at the California Academy of Sciences archives in San Francisco, the CDFG regional headquarters in Yountville, the Russian River Historical Society, and the Sonoma County Water Agency archives. Sources included United States Commission of Fish and Fisheries (USCFF) reports, stocking records, CDFG memoranda, field reports, and dated photographs. California Academy of Sciences and Russian River Historical Society searches were conducted during June 2005. Sonoma County Water Agency and CDFG searches were conducted in 2003.

Underwater Video Counts

Adult fish migrating through the Denil-style fish ladders on either side of Mirabel Dam were counted using underwater video systems (Fig. 1). Each system consisted of a high resolution monochrome camera with a wide-angle (105°) lens in a waterproof case, two high intensity red lights in waterproof housings, and a time-lapse videocassette recorder. The camera and lights were housed in custom manufactured steel cases attached to the fish ladder exits. The system was operated 24 h per day between August and January 2000-2004. Because the fish ladders only function when the rubber dam is inflated, videography ended each year when high flow necessitated deflation of the structure.

The time-lapse recorders captured an image every 0.2 s. Preliminary testing demonstrated that even rapidly swimming fish were captured using this interval. Time- and date-stamped videotapes were reviewed on recorders with slow motion and freeze frame capabilities. Trained tape reviewers recorded species and time of passage. Day and night images were clear, but species identification was not possible during periods of high turbidity immediately after storms. Although species could not be differentiated when visibility was low, family level identification was possible under most conditions.

Spawning Distribution

We counted redds along a 110-km reach of the mainstem from the East and West Branches confluence in the City of Ukiah to the town of Windsor once annually from

2002 to 2004 (Fig. 1). In 2003 and 2004, we also surveyed 22 km of Dry Creek from Warm Springs Dam to the stream's confluence with the Russian River. Although we were primarily interested in describing redd distribution, not abundance, we conducted the one-time surveys after peak fish ladder video counts. The mainstem and Dry Creek reaches were divided into sections and drifted by three person crews in kayaks on consecutive days. Redd locations were recorded using hand-held Global Position System (GPS) receivers. During the 2000-2004 study period, Chinook salmon spawning was observed by local, state, and federal fishery biologists in Russian River tributaries outside our survey area. We interviewed these biologists and included their observations in our description of spawning habitat.

Downstream Migrant Trapping

Juvenile Chinook salmon were captured using one 2.4-m diameter and two 1.5-m diameter rotary screw traps located 50 m below the Mirabel Dam site during spring 2000-2004 (Fig. 1). Trap installation date was dependent on stream flow and ranged from 28 February to 20 April. The traps were fished 24 h per day and checked once daily. We removed the traps when catches declined to near zero between 7 June and 3 July each year.

Captured fish were placed in aerated 45-L ice chests, anaesthetized with CO_2, measured, and caudal fin clipped for genetic tissue sample collection and trap efficiency testing. Trap efficiency was determined by mark-recapture and newly clipped fish were released 0.8 km above the trap site. Recaptured and unmarked fish were released downstream. To reduce handling stress, we suspended marking when water temperature exceeded 21 °C and released fish immediately downstream per our National Marine Fisheries Section 10 permit.

Juvenile abundance was estimated using a stratified-Petersen mark-recapture estimator designed for downstream migrant trap data (Bjorkstedt 2005). The Darroch Analysis with Rank Reduction (DARR) approach to estimating downstream migrant population size ameliorates bias associated with small samples and temporal variation in capture probabilities (Darroch 1961; Bjorkstedt 2005). To help partition the mark-recapture data, we alternated clips weekly between the upper and lower lobes of the caudal fin. We marked up to 50 fish > 60 mm fork length (FL) per day. Fish less than 60 mm FL were deemed too small to adequately mark. The proportion of marked to unmarked fish was used to calculate weekly population estimates using the DARR statistical software package (Bjorkstedt 2005). Because we only marked fish longer than 60 mm FL, no mark-recapture estimates were available for early season catches of smaller fish.

RESULTS

Document Review

The United States Commission of Fish and Fisheries (USCFF) produced annual reports of commercial fishing activities, hatchery operations, and research efforts

throughout the United States in the late nineteenth and early twentieth centuries. Stocking records reported the planting of 55,000 Chinook salmon fry in the Russian River between 1881 and 1907 (USCFF 1910). The first record of a Russian River commercial fishery appeared in the 1892 report. Although species were not identified, 15,240 kg of salmon were landed using gill nets in the lower river and shipped to San Francisco by rail in 1888 (Table 1). In addition to the reported catch, non-commercial landings of salmon were estimated at 68,040 kg. The 1892 report also detailed the number of salmon captured by month during 1888 (Fig. 2). Catch records from 1889 to 1892 specify Chinook salmon, but only provide summary information for Sonoma County (Table 1). However, the total landings, number of anglers, and gear type were similar to the 1888 record. Jordan (1895) noted the capture of less than 4,536 kg of salmon in the Russian River during 1893, but also failed to identify species. Sonoma County fishery data in 1895 and 1899 reported the use of set lines, fyke nets, and gill nets, but did not record landings of salmon. Chinook salmon appear again in the Sonoma County catch in 1915 and 1922 (Table 1). The listing of Sonoma County fishing activities in USCFF reports ended in 1922.

The stocking and catch of Chinook salmon during the mid-twentieth century was reported primarily by the California Department of Fish and Game. Although we found summary references to Russian River fisheries during the 1940s and 1950s, no

Table 1. Commercial salmon fishery data for the Russian River and Sonoma County from United States Commission of Fish and Fisheries Reports (USCFFF). Report authors are indicated when available. The 1892 and 1895 reports detailed Russian River salmon fishing activities but did not include species identification.

Year	Location	Anglers	Gear type	Chinook salmon (kg)	Salmon (kg)	Source
1888	Russian River	15	gill nets	n.a.	15,240	USCFF 1892
1889	Sonoma Co.	18	gill nets	12,161	n.a.	USCFF 1893
1890	Sonoma Co.	19	gill nets	9,696	n.a.	USCFF 1893
1891	Sonoma Co.	19	gill nets	16,627	n.a.	USCFF 1893
1892	Sonoma Co.	19	gill nets	13,081	n.a.	USCFF 1893
1893	Russian River	"few"	n.a.	n.a.	≤4,536	Jordan 1895
1895	Russian River	64	lines[a]	0	n.a.	USCFF 1896
			fyke nets	0		
1899	Sonoma Co.	n.a.	gill nets[b]	0	n.a.	Wilcox 1902
1915	Sonoma Co.	n.a.	gill nets	2,722	n.a.	USCFF 1920
			lines	5,443		
1922	Sonoma Co.	11	haul seine	2,268	n.a.	USCFF 1926
			lines	45,360		

[a] Sturgeon was the only finfish caught in 1895.
[b] No finfish were reported in 1899.

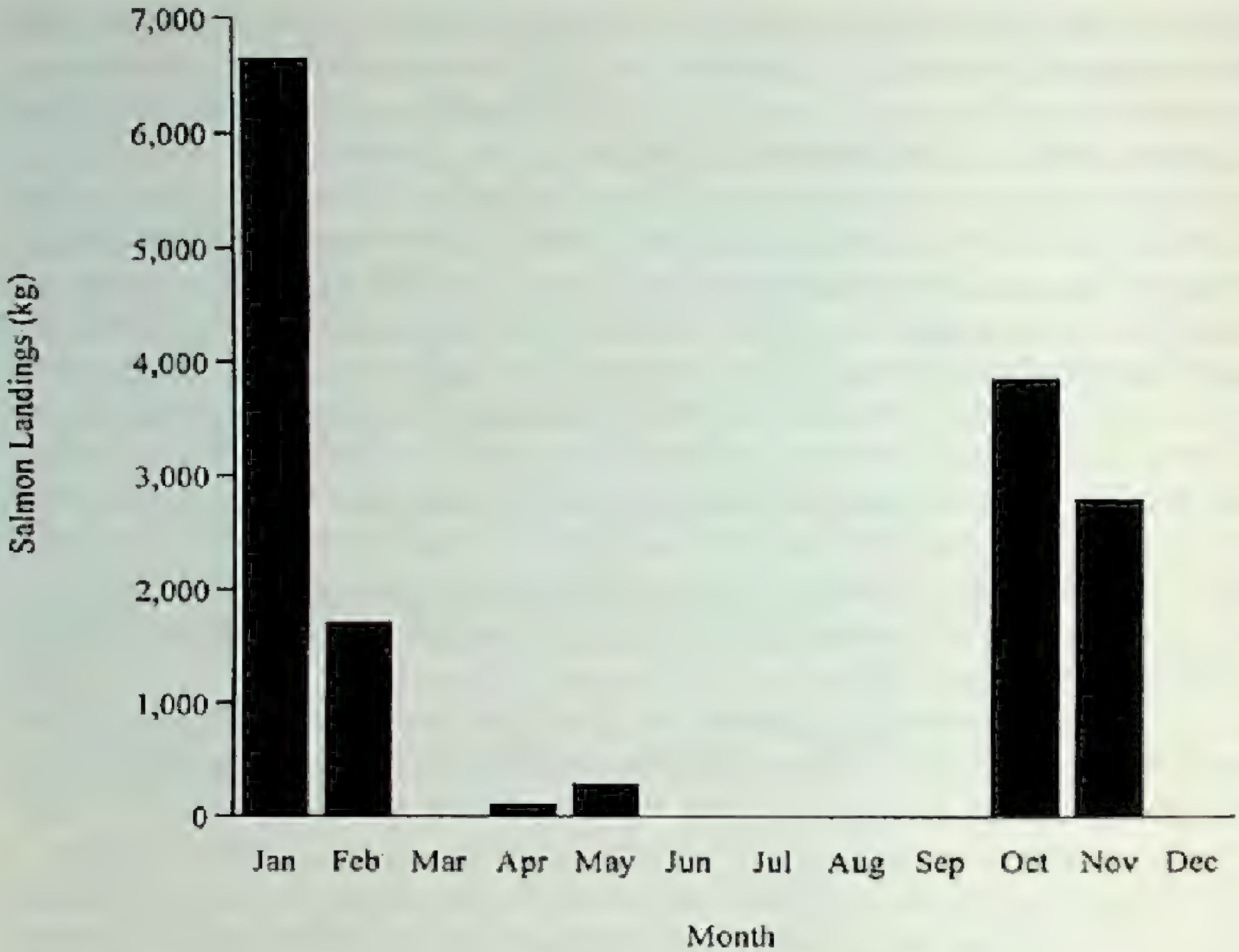

Figure 2. Monthly commercial salmon landings (species not identified) in 1888 from the lower Russian River near the town of Duncans Mills (data from USCFF 1892).

comprehensive sampling surveys were conducted. Rich et al. (1944[6]) reported the presence of a small and sporadic coho salmon run, but no known run of Chinook salmon. Shapovalov (1955[7]) also noted the absence of Chinook salmon and Pintler and Johnson (1956[8]) stated that they were sometimes caught during winter in the lower river but were otherwise rare.

Efforts to establish a spawning population accelerated with the stocking of 2.25 million fry between 1956 and 1960 (Table 2). Surveys conducted from August to mid October 1960 did not find spawning Chinook salmon, but reported the observation of live adult fish and the capture of up to 250 fish by anglers (Day 1961[9]; Hinton 1963[10]). Hinton (1963[10]) noted scattered observations of spawning Chinook salmon, 500-600 fish taken by anglers, and estimated the spawning run at 1,000 fish in 1961. From 1961 to 1970, CDFG planted 1,857,285 juveniles obtained primarily from Coleman National Hatchery in the Sacramento River basin (Table 2). Spawning adults were reported in the upstream portion of the mainstem and large tributaries in 1969 (Vestal and Lassen 1969[11]).

We found only one field survey conducted during the 1970s. From November to March 1970-1973, fyke nets were fished in the lower river to capture adult salmonids

Table 2. Broodstock sources and numbers of juvenile Chinook salmon released in the Russian River from 1950 to 2000. Hatcheries are noted in parentheses.

Time period	Source river	Juveniles	Reference(s)
1951-1960	Klamath, Sacramento (Coleman)	2,250,000	Hinton 1963[10]; Steiner 1996[2]; Myers et al. 1998
1961-1970	Sacramento (Coleman), unknown[a]	1,857,285	Holman 1968[12]; Nokes 1970[13]; Myers et al. 1998
1971-1980	Klamath (Iron Gate)	73,800	Myers et al. 1998
1981-1990	Russian, Eel, Mad, Ocean[b], Silver[b], Wisconsin[c]; Sacramento (Feather)	1,847,140	Estey 1981[14], 1982[15], 1983[16], 1984[17], 1985[18]; Gunter 1986[19], 1987[20], 1988[21], 1989[22], 1990[23]; Myers et al. 1998
1991-2000	Russian, Eel, Noyo[d], Sacramento (Feather)	349,105	Gunter 1991[24], 1992[25]; Cartwright 1994[26]; Williams 1994[27]; Quinones 1995[28], 1996[29], 1997[30], 1998[31], 1999[32], 2000[33]; Myers et al. 1998
Total		6,377,330	

[a]Myers et al. list 879,885 fish during 1969-1970 from an unknown source. [b]Ocean King and Silver King were from private hatcheries. [c]Green River, Washington [d]Myers et al. 1998 list Sacramento (Nimbus) for 1990-94. Noyo eggs may represent Nimbus strain.

for mark-recapture population estimates (B. Cox, California Department of Fish and Game, personal communication). One adult Chinook salmon was captured in December 1970. Summary reports from 1972 to 1991 noted past stocking efforts and estimated annual Chinook salmon returns of 0-500 fish (Anderson 1972[34]; Jensen 1973[3]; Lee and Baker 1975[35]; CDFG 1991[36]).

The CDFG began operating the Don Clausen Fish Hatchery located on Dry Creek in 1980 during the construction of Warm Springs Dam and Lake Sonoma. Between 1981 and 1999, the hatchery released more than 2 million fingerlings and yearlings derived from both out-of-basin and local broodstock (Table 2). Annual juvenile releases and adult returns at Don Clausen Fish Hatchery ranged widely (Table 3). Because yearlings were last released from the hatchery in 1998-1999, hatchery returns after 2002 were the progeny of fish produced naturally in the Dry Creek basin (Table 3).

Underwater Video Counts

Video cameras were installed between August 1 and August 22 in 2000-2004 and were operated continuously until flows necessitated deflation of the dam between November and January. The quality of video images was high, but poor water clarity after storms and the variable period of system operation yielded partial counts of total escapement (Fig. 3). Total counts of adult Chinook salmon ranged from 1,383 in 2001

Table 3. The number of juvenile Chinook salmon released and adults that returned to the U.S. Army Corps of Engineers/CDFG Don Clausen Fish Hatchery located on Dry Creek, a major Russian River tributary. Years extend from July 1 of the first year through June 30 of the second year. Juvenile releases include both fingerlings and yearlings. Adult returns include grilse.

Year	Juvenile releases	Adult returns
1981-82	102,360	0
1982-83	89,650	1
1983-84	66,120	4
1984-85	211,510	8
1985-86	884,520	65
1986-87	126,557	111
1987-88	79,166	304
1988-89	237,450	233
1989-90	49,807	17
1990-91	110,690	99
1991-92	113,525	125
1992-93	8,877	40
1993-94	50,300	21
1994-95	0	85
1995-96	25,923	33
1996-97	31,990	43
1997-98	7,800	49
1998-99	11,730	4
1999-00	0	2
2000-01	0	29
2001-02	0	10
2002-03	0	306
2003-04	0	262
2004-05	0	211

to 6,081 in 2003 (Table 4). Adult fish were first observed in late August and last observed during December, but peak immigration occurred between mid October and mid November each year (Fig. 4). Peak 24-hour counts exceed 1,000 fish on 7 November 2002, 31 October 2003, and 26 October 2004. In addition to Chinook salmon, clear video images of adult steelhead, chum salmon, *O. keta*, pink salmon, *O. gorbuscha*, and Pacific lamprey, *Lampetra tridentata*, were captured during the monitoring period.

Spawning Distribution

We conducted mainstem redd surveys from November 5 to 30 in 2002, 2003, and 2004. Dry Creek surveys were conducted from November 23 to 25 in 2003 and 2004. Adult Chinook salmon were the only fish observed on the spawning grounds. Total

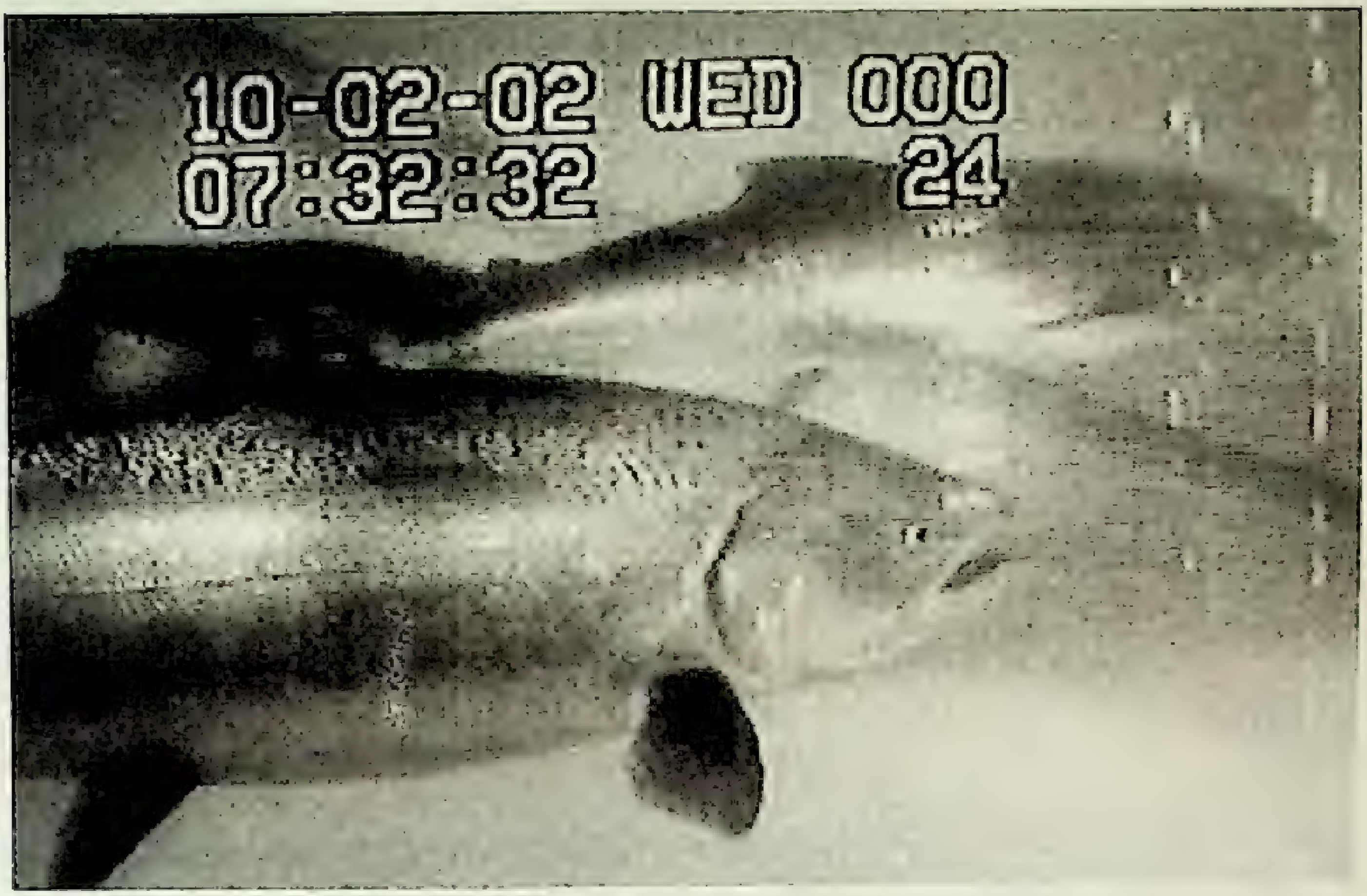

Figure 3. A typical underwater video image of Chinook salmon passing through the west side fish ladder exit at Mirabel Dam, Russian River, CA, on October 2, 2002.

redd counts during the one-time surveys followed the same trend as the number of adults recorded on video. In the mainstem, we found 1,044 redds in 2002, 907 redds in 2003, and 558 redds in 2004. Redds were observed throughout the 110-km reach, but most spawning occurred between Cloverdale at rkm 101 and the East and West Branches confluence (rkm 150) near Ukiah (Fig. 5). In Dry Creek, we counted 256 redds in 2003 and 342 redds in 2004. Redd density also increased in an upstream direction along Dry Creek. Mean redd density from 2003 to 2004 was higher in Dry Creek (14 redds/km) than in the upper mainstem Russian River (10 redds/km). Detailed maps of mainstem and Dry Creek spawning sites can be found in Cook (2004[37]).

In addition to the mainstem and Dry Creek, Chinook salmon spawning was also observed or inferred in four mainstem tributaries (Fig. 1). In 2002, dozens of fish were observed spawning in Santa Rosa Creek (S. Brady, City of Santa Rosa, personal communication). In 2003 and 2004, juveniles were captured in downstream migrant traps on Austin Creek (D. Hines, NOAA Fisheries, personal communication) and Green Valley Creek (D. Acomb, California Department of Fish and Game, personal communication). Redds and Chinook salmon carcasses were also observed in Forsythe Creek during 1999 (S. Harris, California Department of Fish and Game, personal communication).

Table 4. Weekly underwater video counts of adult Chinook salmon that passed Mirabel Dam on the Russian River, CA during the years 2000-2005. Video recording ceased when the dam was removed each year.

	Year				
Week of	2000	2001	2002	2003	2004
1-Aug	0	0	0	0	0
8-Aug	0	0	0	0	0
15-Aug	0	0	1	0	0
22-Aug	1	0	8	0	0
29-Aug	0	3	7	2	1
5-Sep	9	1	18	7	1
12-Sep	38	7	19	20	3
19-Sep	23	12	65	22	8
26-Sep	50	17	1,223	181	16
3-Oct	31	240	113	146	42
10-Oct	115	51	628	512	52
17-Oct	81	10	272	230	651
24-Oct	466	300	153	528	2,287
31-Oct	63	661	505	2,969	185
7-Nov	24	81	2,337	1,282	1,189
14-Nov	182		20	47	221
21-Nov	200		37	92	57
28-Nov	111		14	43	60
5-Dec	19		54		16
12-Dec	14				
19-Dec	17				
26-Dec	1				
2-Jan	0				
Total	1,445	1,383	5,474	6,081	4,789

Downstream Migrant Trapping

The installation date of downstream migrant traps was dependent on stream flow and varied from late February to mid April each year. Juvenile Chinook salmon were captured as early as February but most fish were less than our minimum marking size (60 mm FL) until April. During 2000-2005, weekly catches of outmigrant Chinook salmon slowly increased during March and early April, peaked between late April and mid May, then slowly declined and approached zero by early July (Table 5). Although low numbers of fish were still emigrating when the traps were removed, the sampling period covered the majority of the smolt emigration season. The total number of fish captured ranged from 1,361 in 2000 to 19,319 in 2002 (Table 5). Total trap efficiency was similar each year and ranged from 7 to 11 percent. Mark-recapture population estimates, plus

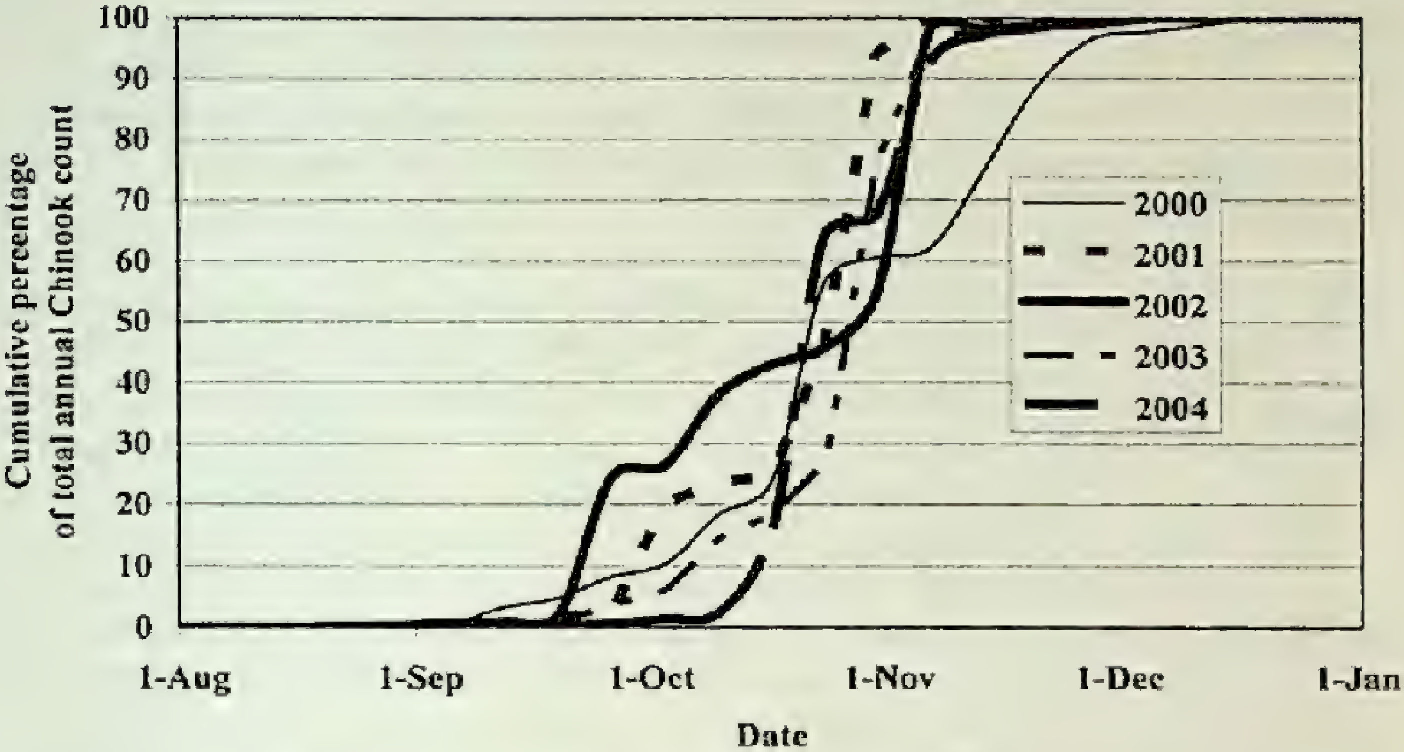

Figure 4. Run timing of adult Chinook salmon in the Russian River, CA, for the years 2000-2004 shown as the cumulative percentage of fish counted at the Mirabel Dam fish ladders.

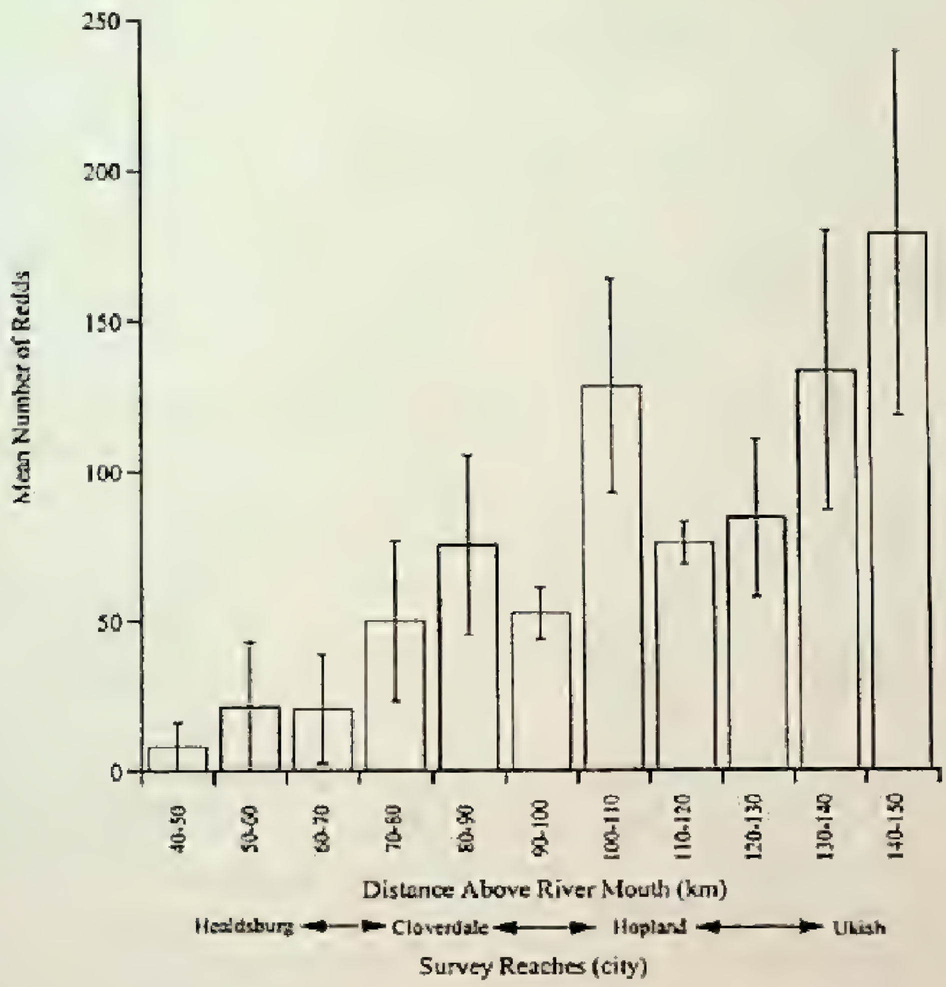

Figure 5. Mean number of redds observed along 10-km sections of the mainstem Russian River for 2002-2004 (n= 3 years). Error bars depict 1 SD. Cities that delineated approximate survey reach boundaries are also shown.

Table 5. Juvenile Chinook salmon captured, marked, and recaptured in rotary screw traps below Mirabel Dam on the Russian River, CA. Estimated trap efficiency applies to the period following initiation of mark-recapture. Total population estimate (N) and error (SE) were calculated using DARR 2.0 software (Bjorkstedt 2005). The traps were not operated during weeks without capture data.

	Year				
Week of	2000	2001	2002	2003	2004
26-Feb			45	332	
5-Mar			74	841	
12-Mar			319	89	
19-Mar			181	169	
26-Mar			[a]797	346	19
2-Apr	41		908	377	63
9-Apr	158		757	[a]176	115
16-Apr	154	122	2,279	[b]17	[a]672
23-Apr	204	720	2,992	[b]60	1,911
30-Apr	169	1,338	4,337		1,845
7-May	121	[a]1,154	1,780	[b]50	1,631
14-May	174	226	2,056	508	552
21-May	106	76	1,755	690	158
28-May	92	64	704	1,461	150
4-Jun	66	22	192	530	125
11-Jun	47		93	374	31
18-Jun	19		46	186	88
25-Jun	10		4	48	9
July 2				3	
Total Catch	1,361	3,772	19,319	6,257	7,369
Total Marked	n.a.	525	2,804	1,072	1,631
Total Recaptured	n.a.	60	253	90	120
Trap Efficiency	n.a.	11 %	9 %	8 %	7 %
Estimated N (SE)	n.a.	20,021 (5,144)	225,135 (37,028)	46,579 (18,252)	91,352 (17,652)

[a]Date when mark-recapture was initiated
[b]Trap operated for a portion of the week due to high flow

the total number of fish captured before marking was initiated, ranged from 20,021 in 2001 to 225,135 in 2002 (Table 5).

DISCUSSION

Our 5-year monitoring results have documented a relatively abundant, widely distributed, and naturally self-sustaining population of Chinook salmon in the Russian River. The paucity of information in the historical record and lack of recent comprehensive field surveys lead researchers to erroneously conclude that Russian River Chinook salmon were either extirpated or scarce (Steiner 1996[2]; Moyle 2002). Although the existence of a population is no longer in question, its origin and historic persistence remain unknown. Our document review and monitoring results, however, may help resolve questions about the history and status of this threatened population.

There are no records indicating Chinook salmon presence or absence in the Russian River prior to the first stocking in 1881 and the existence of a historic wild population has been questioned (Steiner 1996[2]). The Russian River fishery described in 1888 (USCFF 1892) consisted of an unspecified mixture of salmonids. The 1889 to 1891 catch for Sonoma County did not refer specifically to the Russian River, but listed Chinook salmon landings and total catches, gear type, and number of anglers similar to the 1888 record. The one time stocking of 30,000 fry in 1881 was unlikely to create a Chinook fishery of this size. Steiner (1996[2]) cited the 3.6 to 9 kg individual weight of unspecified salmon in 1888 as too small to represent Chinook salmon. However, we routinely observed fish in that size range during video monitoring and redd surveys. During 8 nights from 6 October to 17 November 2003, we trapped fish at one Mirabel Dam fish ladder exit and found the mean weight of 28 Chinook salmon was 4.9 kg. Data from 1888 documented adult salmonids in the lower Russian River during October and November which coincides with the peak immigration period for Chinook salmon entering the Russian River during our 5-year monitoring program.

While we found correspondence between our immigration data and information in the historical record, the legacy of flow manipulation in the Russian River tempers any suppositions about run timing prior to 1908. Russian River flow has been regulated for nearly 100 years and flow manipulation has been implicated as a factor in population decline and cited as evidence that Chinook salmon may have been absent historically. An interbasin water transfer and hydroelectric facility, known as the Potter Valley Project (PVP), began supplementing Russian River flows with Eel River water in 1908 (Beach 2002[38]). While early flow records are sparse, PVP modifications in 1922 and the completion of Coyote Valley Dam and Lake Mendocino in 1959 caused a 20-fold increase in summer and fall Russian River base flows (Steiner 1996[2]). Historically intermittent flow in late summer likely encouraged formation of a seasonal sandbar at the river mouth that may have prevented salmonid immigration before heavy fall and winter rains.

Moyle (2002) concluded that the historic Russian River hydrologic regime was appropriate to support Chinook salmon and the range of river entry dates suggested by our data supports this contention. Although we found that adult fish entered and

held in the lower river during August and September, the peak immigration period is often coincident with the first heavy fall rains that would have allowed access to an ancestral population. If current run timing has advanced in response to flow augmentation, however, the phenology of an historic population could have changed within 100 years. Adult migration and spawn timing are genetically controlled traits that can change rapidly in response to anthropogenic and environmental selective factors (Quinn et al. 2001; Quinn 2005). If early returning Russian River adults encountered favorable spawning conditions created by artificially stable fall flows, adult migration timing could have shifted earlier over the 25 to 30 generations since flow augmentation began.

The altered flow regime may have also helped strays from adjacent river systems and non-native stock transfers establish the current population. The possibility that Russian River Chinook salmon are descendants of Eel River fish, mistakenly homing to water transferred from their natal watershed has persisted in the lore of Russian River fisheries. Most of the more than 6 million juveniles stocked from 1950 to 1999 originated from sources outside the Russian River basin including the Klamath, Eel, Noyo, and Sacramento rivers. Recent genetic analyses, however, have demonstrated separation between Eel River, Russian River, and Central Valley Chinook salmon populations (Hedgecock et al. 2002; Bjorkstedt et al. 2005). While the current Russian River Chinook salmon population is not composed of recent Eel River or Central Valley strays, the extensive planting of out-of-basin fish within the California Coast Chinook salmon ESU has likely blurred patterns of historic genetic population structure (Bjorkstedt et al. 2005). Although we cannot discount the possibility that introduced juveniles yielded the current population, it should also be noted that the most recent and extensive artificial propagation effort at Don Clausen Fish Hatchery failed to generate sustainable adult returns.

The low adult returns to Don Clausen Fish Hatchery appear to contrast our adult video counts and spawner distribution surveys. Our video counts are only minimum population estimates but were 20 to 50 times higher than hatchery returns from 2000 to 2004. Because the hatchery last released yearlings in 1998, returns after 2002 were the progeny of fish that spawned naturally in Dry Creek. Our one-time surveys in Dry Creek found more than 250 redds in 2003 and 2004.

The incongruence of hatchery records and our recent observations are indicative of similar trends in the historical data. We found historical documentation of stocking efforts throughout the Russian River basin, but field surveys of spawner abundance and distribution were sparse and inconsistent. Field surveys that described adult Chinook salmon presence appeared to correspond with prior periods of juvenile stocking. However, the limited timing, duration, and spatial extent of these surveys may have failed to detect a widely distributed population. Agrawal et al. (2005) compiled distribution data prior to the year 2000 throughout the California Coast Chinook salmon ESU and found documentation of spawning Chinook salmon in 54 km of streams in the Russian River basin. Professional biologists queried during the investigation suspected salmon were also present in an additional 148 km of habitat (Agrawal et al. 2005). The observation of fish in only 25% of their potentially occupied habitat makes it unlikely that observers could have reliably estimated population abundance. We suspect

similar or less rigor in historical population estimates that were based largely on professional judgment. We found Chinook salmon spawning along 132 km of mainstem Russian River and Dry Creek habitat. It is unlikely that our monitoring program coincided with the sudden appearance of 1,383 to 6,081 adult fish. Since recent genetic studies demonstrated that the Russian River Chinook are not strays from nearby river systems, it is most likely that some level of escapement was occurring in the river for an unknown period of time. The abundance of Chinook salmon throughout the ESU has undoubtedly declined (Myers et al. 1998), but the extent of the decline and trends prior to 2000 are impossible to determine in the Russian River.

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ABUNDANCE AND IMPACTS OF FALLOW DEER LEKS AT POINT REYES NATIONAL SEASHORE

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ABSTRACT

Fallow deer, *Dama dama*, were released at Point Reyes National Seashore in the 1940s. A population of about 860 of these non-native deer are now well-established within the park. Fallow deer have an unusual mating system. During the fall, males establish areas known as leks where they display to potential mates. A fallow deer lek is typically an area of 100 - 150 m^2 and usually includes 2-5 males. Using their hooves and antlers, each male clears away most or all of the vegetation and digs a rutting pit that he defends throughout the breeding season. A total of 159 fallow deer leks was located within the 298.8 ha of our study areas. In the Olema Valley, where fallow deer densities are high, there were 116 leks, compared with 43 in the similar sized Estero trailhead study area, where deer density was moderate. A total of 705 rutting pits was found in the two study areas, with a mean of 5.1 pits per lek in the Olema Valley and 2.5 for Estero trailhead. The leks and associated pits have resulted in damage to both the ground and the associated vegetation, especially in riparian areas.

INTRODUCTION

Only two species of ungulates (hoofed mammals) are native to Marin County, tule elk, *Cervis elaphus nannodes*, and Columbian black-tailed deer, *Odocoileus hemionus columbianus*. In the 1940s, European fallow deer, *Dama dama*, obtained from the San Francisco Zoo, were released at Point Reyes, Marin County, California. When Point Reyes National Seashore was established in 1962, fallow deer were well established within that area. The fallow deer population was estimated to be 500 in 1973 by John Wehausen[1] and increased to 860 by 2005 (National Park Service, unpubl. data).

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Fallow deer have an unusual mating system. During the fall mating season (or rut), males establish areas (leks) where they display to potential mates (Hirth 1997). This behavior is unique among deer and elk, but has been described in several species of other ungulates (Uganda kob, *Adenota kob*; topi, *Damaliscus lunatus*; waterbuck, *Kobus ellipsyprymnus*; Kafue lechwe, *Kobus leche*; and blackbuck, *Antilope cervicapra*; Isvaran 2005). Formation of leks by ungulates decreases the number of aggressive encounters in which dominant males are involved when the local density of males becomes high, because the spatial stability of territories in leks reduces the number of aggressive encounters among males (Hovi et al. 1996, Pélabon et al. 1999).

A fallow deer lek is typically an area of 100 - 150 m^2 and usually includes two to five males. Using their hooves and antlers, each male clears away most or all of the vegetation and digs a rutting pit that he defends throughout the breeding season. Stenström et al. (2000) described rutting pits in a Swedish population of fallow deer as:

". . . large patches of bare soil found at the center of mating stands where most of the rutting activities take place. . . . Scrapes are small patches of bare soil found throughout the areas of deer activity. Only bucks showed any interest in scrapes. Within a 10-day period half the scrapes were rescraped at least once. Larger scrapes were more frequently rescraped than smaller ones. Frayings, i.e. removal of bark and subsequent scent marking on bushes and small trees close to scrapes, also had a positive effect on the frequency of rescraping. . . . fallow deer bucks in our study do not seem to mark territorial boundaries, rather the intensity of markings tends to decrease with distance from the rutting pit suggesting that scraping may instead be used in male status signaling."

Establishing and defending a rutting pit is energetically expensive. Apollonio et al. (1989) concluded that:

"Body condition appears to be an important determinant of male copulatory success, because only males in superior condition could defend a lek territory for up to two weeks. Males do not feed while defending lek territories. Foraging ability during the year probably determines condition at the onset of the rut. Females appear to choose mates at least partially on the basis of location, preferring males located near traditional routes. Females may ultimately select mates in the best body condition."

In the fall of 2005, we initiated a study of fallow deer leks in two study sites at Point Reyes National Seashore. The goal of this work was to determine the distribution and size of leks, and to evaluate the impact of both the leks and the associated rutting pits on the soil and vegetation.

STUDY AREAS

Our study was conducted in two areas at Point Reyes National Seashore, the northern portion of the Olema Valley and an area around the Estero trailhead (Fig. 1), Marin County, California. The two study areas were selected to represent areas of high and medium fallow deer density.

The Olema Valley was typical of areas within the Seashore that have high densities of fallow deer, based on combined aerial and ground counts conducted in January 2001

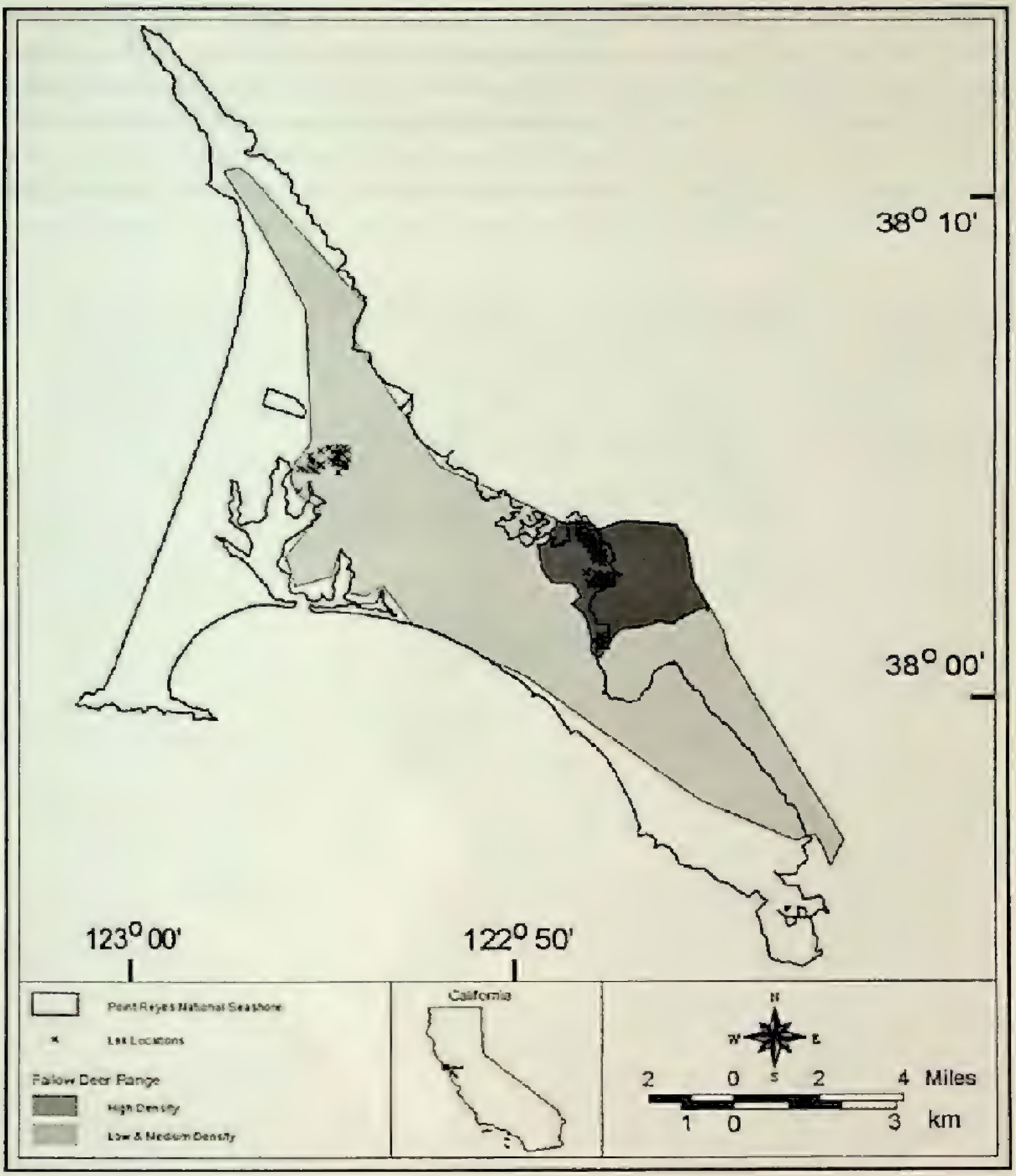

Figure 1. Distribution of high and medium/low density areas for fallow deer at Point Reyes National Seashore, California. Each X marks the location of a lek within our two study areas (see Fig. 2 and 3).

(Gates[2] 2001). Initially, we intended to survey the entire high density area, but it quickly became obvious that the number of leks and the time required to document each lek would preclude a complete survey. Hence, we restricted our work to an area that was

[2]Gates, N. 2001. Aerial and ground censuses of non-native deer, November 2000 and January 2001, Point Reyes National Seashore. National Park Service unpublished report, Point Reyes National Seashore, Point Reyes, California, USA. 21 pp.

bounded by features that were readily discernable in the field (e.g., Olema Creek, Bear Valley Road, fence lines). The areas surveyed included Divide Meadow, Bear Valley, and portions of the pasture and riparian habitat along Olema Creek. The Olema Valley study area was 147 ha in size. The predominant vegetation was coast live oak, *Quercus agrifolia*, and California bay, *Umbellularia californica*, woodlands; red alder, *Alnus rubra*, and willow, *Salix* sp., riparian zones; and grassy meadows and pastures (Fig. 2).

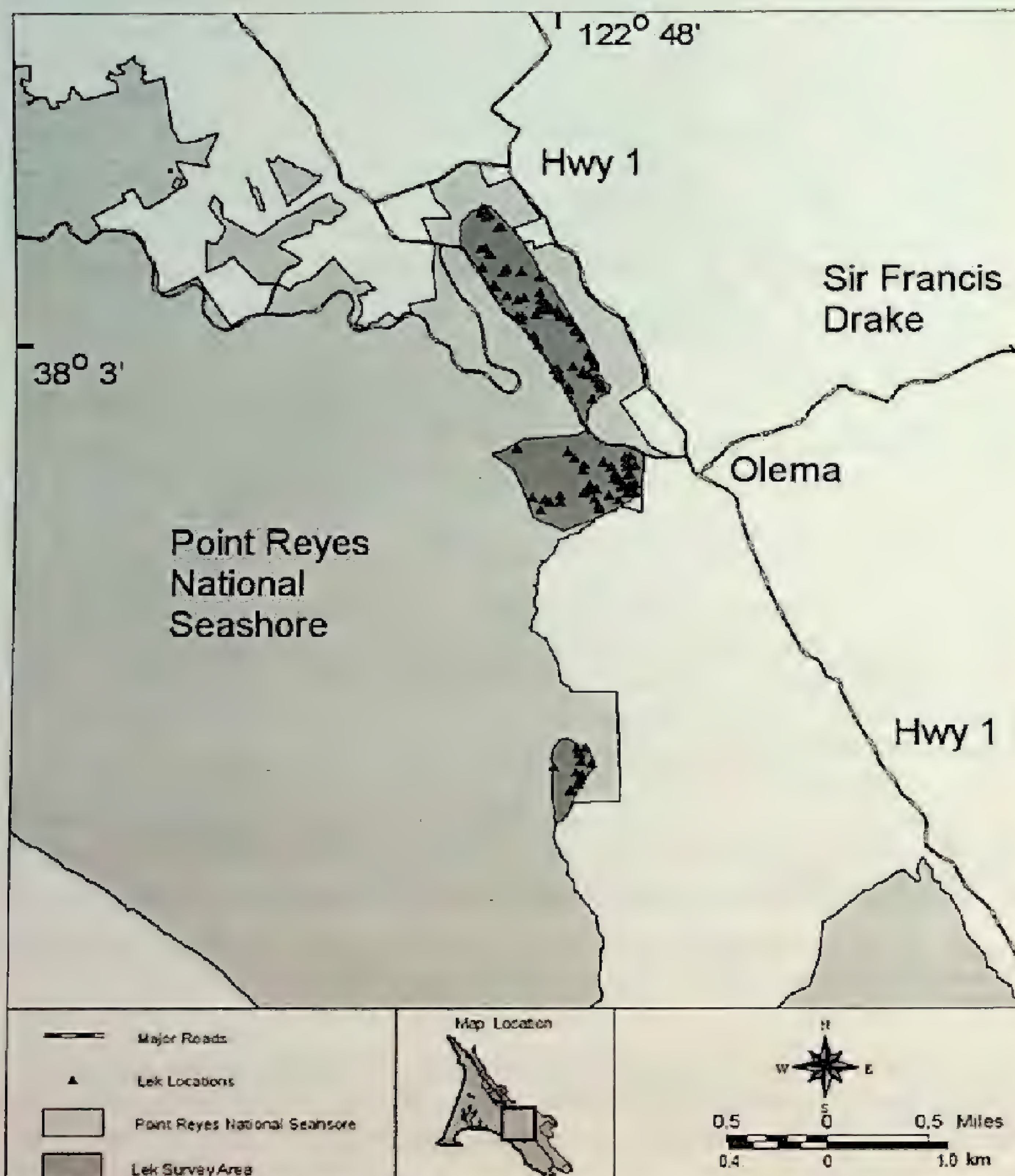

Figure 2. Fallow deer leks in the Olema Valley study area, Point Reyes National Seashore.

An area similar in size was delineated near the Estero trailhead for surveys in the moderate density area. As with the Olema Valley study area, the Estero trailhead area was defined by using a combination of fence lines, roads, and natural features. The Estero trailhead area was selected as representative of an area with medium densities of fallow deer[1]. The Estero study area was 152 ha, roughly equal to the Olema Valley study area. The primary vegetation was coastal scrub dominated by coyote brush, *Baccharis pilularis*, and riparian zones with red alder, and pasture grasslands (Fig. 3).

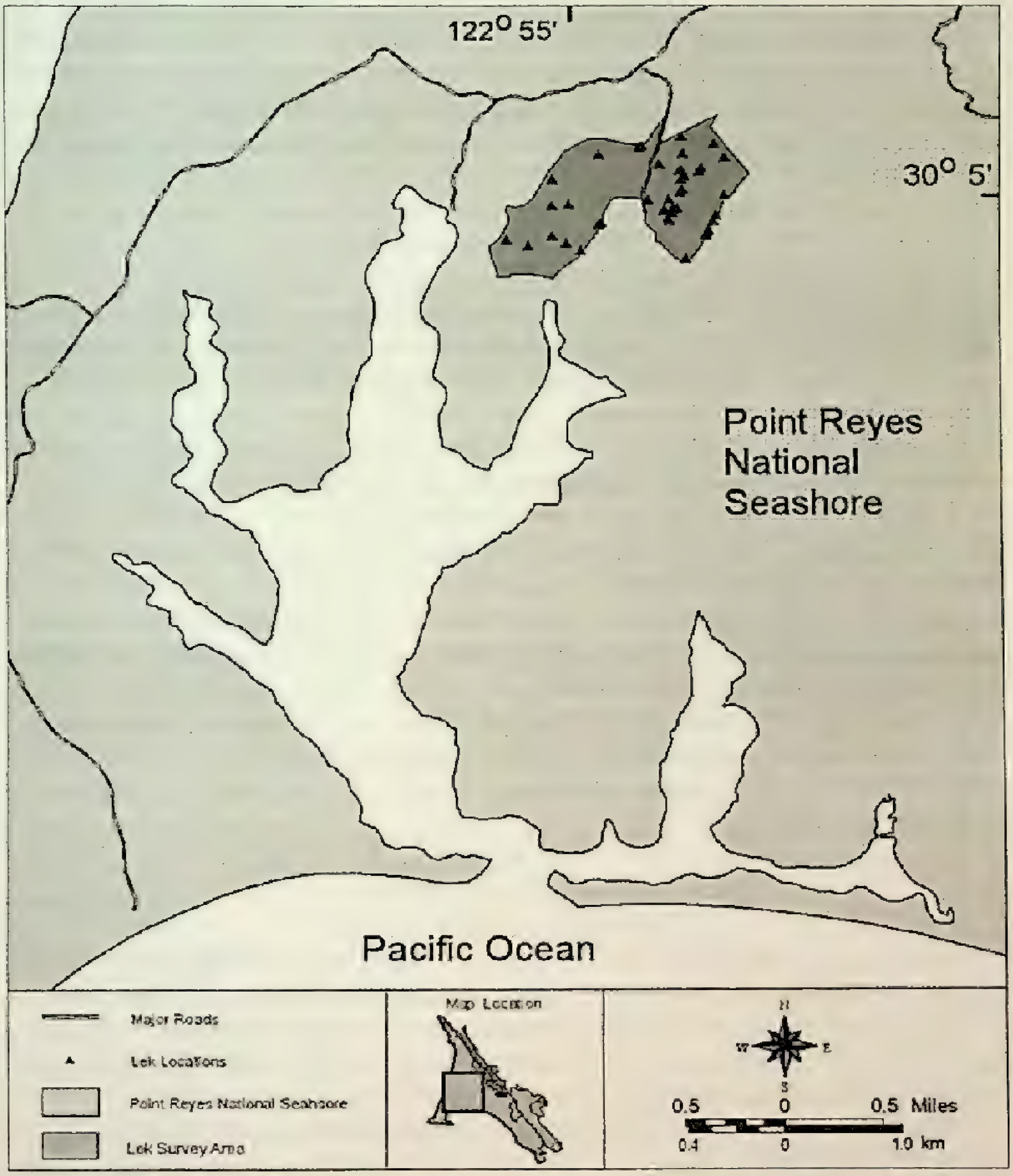

Figure 3. Fallow deer leks in the Estero trailhead study area, Point Reyes National Seashore.

METHODS

Leks were located by conducting visual surveys for fallow deer during, and shortly after, the fall lekking season (3 Oct - 6 Dec 2005). A total of 202 hours was spent conducting surveys. Fallow deer surveys were carried out at dawn from hilltop vantage points. Treelines and grasslands were scanned with binoculars to locate congregations of fallow deer, damaged vegetation, or bare ground. These areas subsequently were investigated to determine whether or not a lek was present. By repeatedly surveying the entire study area, we were confident that few, if any, leks were overlooked.

At each lek, we noted the predominant vegetation, recorded the condition of the soil and vegetation, measured the length and average width of the lek, and measured each individual rutting pit. We photographed leks and rutting pits, and data were recorded with a PDA (Personal Digital Assistant) for downloading into a Microsoft Access database.

Delineating Leks and Rutting Pits

Only areas with disturbed ground or rutting pits were recorded as leks. Pits ranged from shallow depressions where the vegetation had been scraped away to trenches over 50 cm deep. Areas that showed only vegetation damage and lacked ground disturbance, were not scored as leks. Areas with obvious cattle impacts or sites with no discernable deer sign (hoof prints, scat, urine stains, antler scrapes, or deer present) were not counted as leks; hence, our estimate of lek density was conservative.

Leks tended to be concentrated linearly along the treelines at margins of fields. Since many of these areas had a nearly continuous band of disturbance, it was difficult to define individual leks. We marked the end of a lek when there were at least 20 m of undamaged ground between leks. The length and average width of the disturbed ground were measured with a digital range finder. These measurements were used to calculate the area for each lek.

Within a lek, fallow deer bucks excavate numerous rutting pits. The length and width of each pit were measured with a fiberglass tape. Pit depth was measured with a ruler. These measurements were used to determine the total area of excavated ground and the depth of the pits.

Vegetation Condition

In addition to recording the predominant vegetation associated with each lek, vegetation condition was evaluated. Disturbed ground, damaged foliage, damaged bark, and exposed roots were noted. Disturbed ground occurred where the herbaceous cover had been scraped away and resulted in bare soil or excavated rutting pits. Damaged foliage included leaves, twigs, or branches that had been shredded or broken. Damaged bark was noted where fallow deer had used their antlers to break, tear, or scrape off the bark of trees or shrubs. Exposed roots were found in some of the deeper pits where the roots of trees were damaged and exposed. Damaged vegetation that was

not closely associated with a lek was ignored, even though it might have been caused by fallow deer.

Native black-tailed deer feed on buds, twigs, sprouts, leaves, fruit, and flowers of woody plants. We never observed these deer in or around fallow deer leks, probably because fallow deer tend to be behaviorally dominant (Natalie Gates, pers. comm.). Beef cattle were present in all of the Estero trailhead study area and part of the Olema Valley study area. Cattle sometimes rub on vegetation and cause discernable vegetation damage, but we did not observe this behavior at fallow deer leks. Additionally, most of the vegetation damage we observed was in riparian areas where cattle had been excluded by fencing.

During our initial surveys, we did not quantify vegetation condition at each lek, so we revisited 22 randomly selected leks in the Olema Valley to record the condition of both the soil and vegetation in more detail. We used the scoring system of Cole (1989a, b) to evaluate the impacts of fallow deer. At each lek, we scored ground surface disturbance, percent vegetative cover, damage to live trees, and presence of exposed roots. Scores ranged from 1-4 for surface disturbance and vegetation cover, and 1-3 for the other two categories. A score of 1 represented no damage or 50-100% vegetation cover, while the highest scores represented the most extreme damage or lack of vegetation cover; for details, see Fellers and Osbourn (2006). We made no attempt to quantify damage to individual trees or to assess likelihood of tree death resulting from the damage.

Data Collection and Mapping

UTM coordinates were recorded using a Garmin XL GPS unit (www.garmin.com). ArcView 3.3 software (ESRI, www.esri.com/software/arcgis/arcinfo/index.html) software was used to plot lek locations and to determine the size of the two study areas. A digital camera was used to document leks, rutting pits, and damaged vegetation. Bucks displaying and actively digging or shredding foliage were also photographed, as were groups of does. Photographs were also taken of deer scat, hoof prints, and urine stains as evidence of deer use. Statistical analysis was conducted using Statistix 8.0 software (Analytical Software, www.statistix.com) and an $\alpha = 0.05$.

RESULTS

Leks and Rutting Pits

Most leks were found at the edge of a woodland or at the edge of the low-hanging part of the canopy of isolated trees. Some rutting pits were more than 50 cm deep (Fig. 4), and often surrounded by an even larger area cleared of all vegetation. Other leks had only a modest depression and were identified by the lack of vegetation along with associated fecal material, hoof prints, and damage to woody vegetation. Rutting pits in close association with bushes and trees often were associated with significant damage to the woody vegetation, including broken branches, stripped bark and,

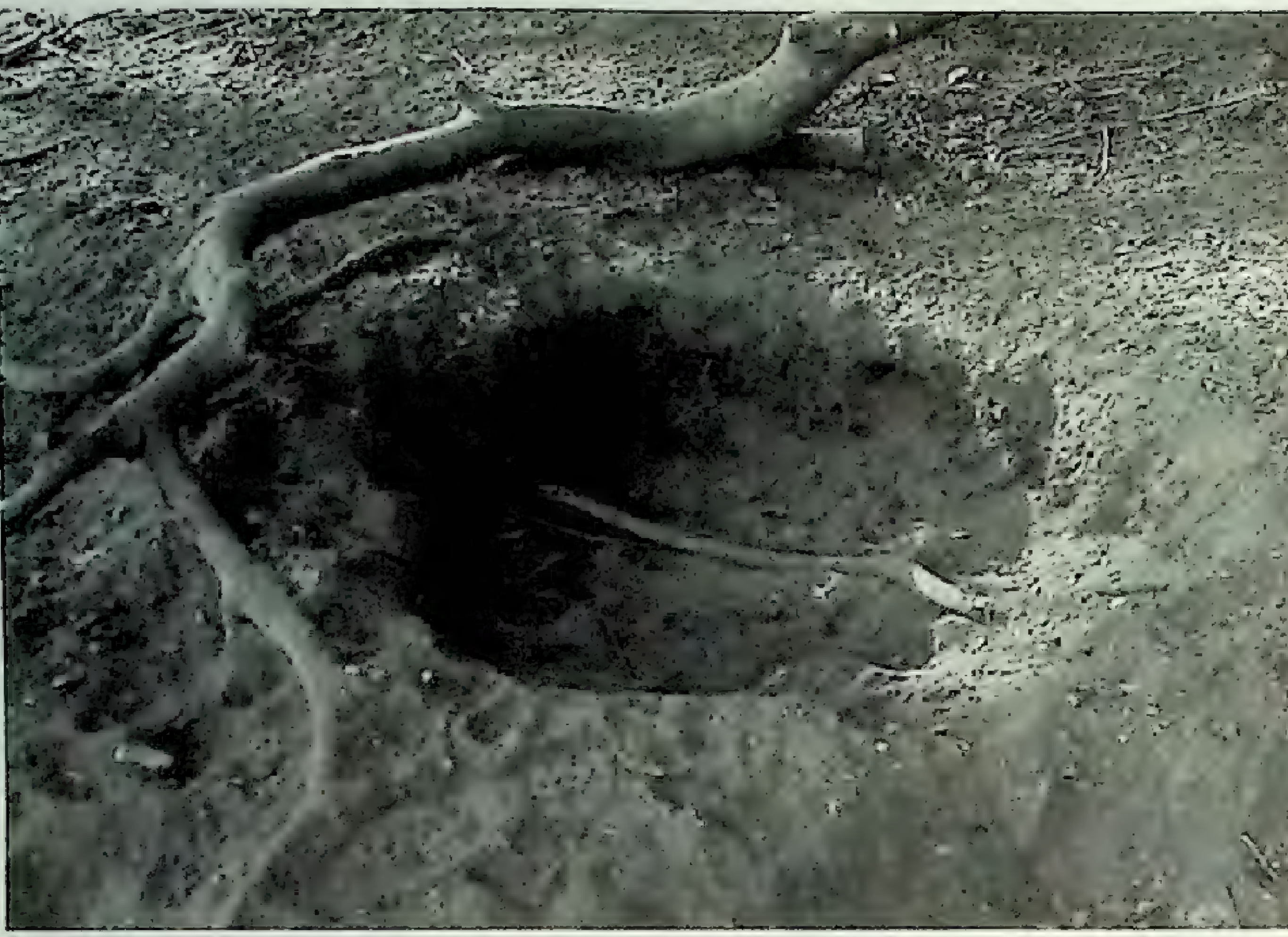

Figure 4. Rutting pit and bare ground associated with a fallow deer lek in the Olema Valley, Point Reyes National Seashore.

sometimes, girdled trees. Fallow deer were observed using their antlers to clear vegetation, rub the trunk of trees, break limbs, and dig pits. Vegetation was sometimes caught in their antlers (Fig. 5).

A total of 159 fallow deer leks was located within the 298.8 hectares surveyed at Point Reyes National Seashore (Table 1). In the Olema Valley, there were 116 leks, compared with 43 in the Estero trailhead area. The mean dimensions of a lek were 13 x 7 m with an area of 115 m^2 (SD = 132, range 1 - 840 m^2). The total area of the leks in the Olema Valley was 16,188 m^2, while the area at the Estero trailhead was 2,136 m^2, for a combined total of 18,324 m^2. This was 0.6% of the 298.8 ha surveyed. There was a notably higher proportion of the Olema Valley study site that was part of a lek, 1.1 % compared to 0.1 % at Estero trailhead. In the Olema Valley, there were 0.8 leks per ha, while in the Estero trailhead area there were 0.3 leks per ha (Table 1).

A total of 705 rutting pits was found in the two study areas, with a mean area of 2.6 m^2 (SD = 3.0, range 0.04 - 50 m^2) for each pit. The mean number of pits per lek was 5.1 in the Olema Valley and 2.5 for Estero trailhead. The total combined area of excavated ground in rutting pits was 1,821 m^2, or 0.06% of the area surveyed, approximately 10% of the lek area. Eighty-five percent (598) of pits were found in the Olema Valley study area. Though fewer in number, the pits at the Estero trailhead were larger (3.3 m^2) than the pits in Olema Valley (2.4 m^2).

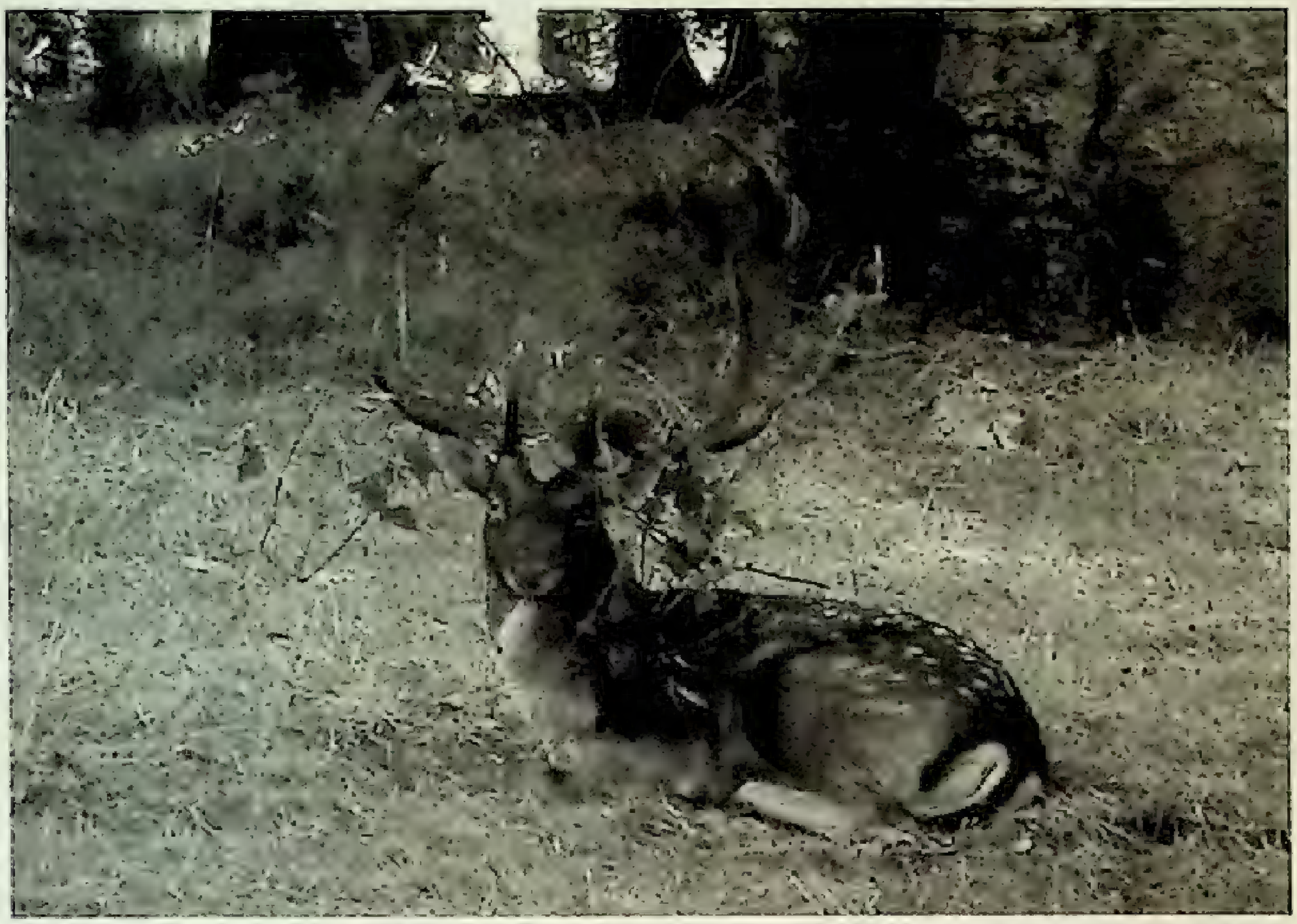

Figure 5. Male fallow deer with vegetation caught in his antlers, Olema Valley, Point Reyes National Seashore.

Table 1. Number of fallow deer leks and rutting pits in two study areas at Point Reyes National Seashore. Numbers in parentheses are Standard Deviations.

	Olema Valley	Estero Trailhead	Combined
Study area size (ha)	147.2	151.6	298.8
Number of leks	116	43	159
Leks per ha	0.8	0.3	0.5
Mean lek area (m^2)	140 (+142)	50 (+60)	115 (+132)
Total lek area (m^2)	16,188	2,136	18,324
Percent lek area (m^2)	1.1 %	0.1 %	0.6 %
Number of rutting pits	598	107	705
Total pit area (m^2)	1,463	358	1,821
Percent study area as pits	0.10 %	0.02 %	0.6 %
Mean number pits/lek	5.1 (+5.1)	2.5 (+1.9)	4.4 (+4.6)
Mean pit depth (cm)	10 (+9)	6 (+5)	9 (+9)
Maximum pit depth (cm)	60	15	60

Vegetation Condition

There was vegetation damage at 110 (69.2%) of the leks. Damaged foliage was present at 102 (64.1%) of leks. During initial surveys for leks, sites were often located by broken live oak or California bay branches that were visible from considerable distances. Low branches and bark adjacent to rutting pits were often heavily damaged. On several occasions, bucks were observed thrashing vegetation with their antlers, digging in the rutting pits, and displaying at their lek. Bark damage was recorded at 72 (45.3%) of the leks; exposed roots were documented at 30 (18.9%) of leks. In addition to having nearly three times as many leks, the Olema Valley study area had a higher percentage of sites with damaged foliage and with damaged bark, but the result was not statistically significant ($c^2 = 3.16$, df = 2, $p = 0.206$).

Vegetation damage was greater in riparian areas (compared with non-riparian) for both the damaged foliage and damaged bark categories (Table 2). In riparian areas, willows and alders were the trees most often observed with damage. Several alders were completely girdled. Less commonly, there were exposed roots, especially in the Estero trailhead area (Table 2). Overall, there was more damage in riparian areas. The results approached statistical significance ($c^2 = 5.74$, df = 2, $p = 0.057$).

In our quantitative evaluation of the vegetation and soil at 22 random sites, surface disturbance ranged from 0 (no disturbance) to 4 (ground surface highly disturbed with extensive areas of bare ground) with a mean score of 1.6 and a median of 2. The mean score corresponds to a damage level between "Little disturbance to ground cover" and "Noticeable disturbance to litter or vegetation" (Cole 1989a, b). Both vegetation cover and live tree damage had a mean and median score of 1.0. There were no roots exposed in the sample plots.

Table 2. Vegetation damage at fallow deer leks at Point Reyes National Seashore. Percentages are the proportion of leks in riparian or non-riparian areas that exhibited vegetation damage.

	Olema Valley	Home Ranch	Combined
Riparian			
Shredded Foliage	88%	88%	84%
Damaged Bark	82%	100%	88%
Exposed Roots	6%	38%	16%
Non-riparian			
Shredded Foliage	71%	24%	76%
Damaged Bark	45%	18%	54%
Exposed Roots	20%	18%	22%

DISCUSSION

Fallow deer are one of the few mammals where males gather in groups and display to potential mates on leks. As part of the display, males dig rutting pits with their hooves and antlers, and scrape bushes and trees adjacent to the pits. This results in soil disturbance, loss of vegetation, and occasional damage to the trunks and limbs of nearby vegetation. The extent of the impacts observed in our study was related to the density of fallow deer. Density of fallow deer was higher in the Olema Valley and lek impacts were greater in that area. The Olema Valley had a greater mean lek area, total lek area, percentage of total area as leks, mean number of rutting pits per lek, percentage of total area as rutting pits, and mean pit depth (Table 1). The density of rutting pits was much less in the Estero trailhead study area, likely because of the smaller fallow deer population there. More than 1 % of the total land area surveyed was impacted by lek damage, with riparian areas being disproportionately affected. For example, in riparian areas, there was bark damage at 88% of the leks, and 84% of the leks had damaged foliage (Table 2).

Fallow deer are having a measurable impact on the soil and vegetation at Point Reyes. In the Olema Valley, there were 0.8 leks per ha, while the Estero trailhead area had 0.3 leks per ha. The primary habitat impact of leks at Point Reyes was caused by the digging of rutting pits that resulted in a loss of soil and vegetation. At the peak of the rut, pits were found commonly in Olema Valley, especially at the woodland/grassland interface, where fallow deer congregated. The total number of rutting pits was 705, with a total area of 1,821 m^2. Pélabon et al. (1999) reported that the formation of leks in ungulates is "a mating tactic that aims at decreasing the number of aggressive encounters in which dominant males are involved when the local male density becomes too high." If the fallow deer population continues to increase, the number of leks, rutting pits, and the associated habitat damage likely will increase.

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W. Rehlaender conducted the detailed soil and vegetation evaluations and provided those data to us for analysis. P. Kleeman provided assistance in data management. K. Dhillon assisted with the initial surveys for fallow deer leks and with general advice on the location of fallow deer within the seashore. D. Schriokaurer and A. Ryan provided GIS mapping assistance. N. Gates offered advice throughout the development and implementation of the project. J. Fellers, R. Golightly, K. Jenkins, P. Kleeman, and D. McCullough provided comments on an earlier draft of this report. We greatly appreciate the assistance of all of the above.

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OCCURRENCE OF A EULACHON, *THALEICHTHYS PACIFICUS*, IN THE LOWER SACRAMENTO RIVER, CALIFORNIA

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The eulachon, *Thaleichthys pacificus* Richardson (1836), is a large, anadromous smelt (Family Osmeridae) that occurs throughout the northeastern Pacific Ocean. It spawns in coastal streams and rivers from Humboldt County in northwestern California (Moyle 2002) to the eastern Bering Sea (Hay and McCarter[1] 2000). Spawning runs in California have been documented as far south as the Mad River and Redwood Creek, Humboldt County, but the primary California population occurs slightly to the north of these streams in the Klamath River, Del Norte County (Odemar 1964). While spawning runs of eulachon in these streams were large enough in 1963 to support a commercial fishery (Odemar 1964), the overall abundance of eulachon in this area has apparently declined substantially since the 1970s (Moyle 2002), and the fish is currently on the State of California's Watch List of Fish Species of Special Concern[2].

The oceanic and estuarine distribution of eulachon extends to the south of its known spawning distribution in fresh water. Odemar (1964) reported the capture of eulachon in marine waters off the Mendocino and Sonoma County coasts as far south as the vicinity of Bodega Head. More recent observations by the California Department of Fish and Game (CDFG) include a eulachon collected at the J.E. Skinner Fish Facility in Contra Costa County, California within the San Francisco Bay-Delta complex in 1984[3], and two eulachon collected in San Francisco Bay during fishery surveys in April 1999

[1]Hay, D., and P. B. McCarter. 2000. Status of eulachon *Thaleichthys pacificus* in Canada. Canadian Stock Assessment Secretariat. Research Document 2000/145. (available at http://www.dfo-mpo.gc.ca/csas/)

[2]Moyle, P. B., R. M. Yoshiyama, J. E. Williams, and E. D. Wikramanayake. 1995. Fish species of special concern in California, 2nd edition. California Department of Fish and Game, Sacramento.

[3]FishBase 2004. Occurrences of *Thaleichthys pacificus*. http://fishbase.sinica.edu.tw/museum.SpecCollectionList.php. (accessed in February 2006).

and April 2003 (K. Hieb, Associate Marine Biologist, CDFG, personal communication). In addition, Moyle (2002) reported a CDFG observation of eulachon in the Pacific Ocean off Point Buchon, San Luis Obispo County.

Here, we report on a mature male eulachon captured in a rotary screw trap, 0.8 km downstream from Knights Landing on the lower Sacramento River (river km 142; 38°47'449" N, 121°41'533" W) on 27 January 2006. Two, 8-ft diameter rotary screw traps are operated by the CDFG at this location to monitor emigration of juvenile salmonids from the upper Sacramento River basin (e.g., Snider and Titus[4] 2000). Mean water temperature was 9.5°C during the sampling interval when the eulachon was captured. When collected, the fish was swimming weakly on the surface of the water in the live well of the trap. The specimen was bluish-brown on the back with silver sides, and had patches of fungus on its back and sides. It measured 204 mm FL (217 mm TL) and weighed 60.0 g. M. Brown (Environmental Scientist, CDFG) and the junior author identified the species independently, using the key in Moyle (2002). The specimen was distinguished from other California osmerids by its complete lateral line and relatively large size (Table 1), and the presence of concentric striations on its opercula (Miller and

Table 1. Selected meristic characteristics of California osmerids. Data are from Miller and Lea (1972) and Moyle (2002). L = left fin or side, R = right fin or side.

	Fin ray counts				
Species	Dorsal	Anal	Pectoral	Lateral line pores	Max length (mm)
Current specimen	11	21	11 L / 11 R	70 L / 70 R	204 FL / 217 TL
Delta smelt, *Hypomesus transpacificus*	9 – 10	15 – 17	10 – 12	8 – 9	115
Surf smelt, *H. pretiosus*	8 – 11	12 – 17	14 – 17	4 – 12	255
Wakasagi, *H. nipponensis*	8 – 11	14 – 17	11 – 14	54 – 60	120
Longfin smelt, *Spirinchus thaleichthys*	8 – 10	15 – 22	10 – 12	14 – 21	150
Night smelt, *S. starksi*	8 – 11	15 – 21	10 – 11	16 – 24	140
Eulachon, *Thaleichthys pacificus*	10 – 13	18 – 23	10 – 12	70 – 78	305
Whitebait smelt, *Allosmerus elongatus*	9 – 10	14 – 17	12 – 14	c. 20	230

[4]Snider, B., and R. G. Titus. 2000. Timing, composition and abundance of juvenile anadromous salmonid emigration in the Sacramento River near Knights Landing, October 1998 – September 1999. California Department of Fish and Game, Stream Evaluation Program Technical Report No. 00-6.

Lea 1972, Moyle 2002). A scale sample and the sagittal otoliths were taken to age the fish, the stomach was examined for food, and the testes were dissected from the fish and weighed to determine the gonadosomatic index (GSI), with gonadal weight expressed as a percentage of body weight. Digital photographs were taken for identification and documentation of the specimen (Fig. 1). The specimen is archived at the U.C. Davis Museum of Wildlife and Fish Biology (Ref #WFB-80-06-03).

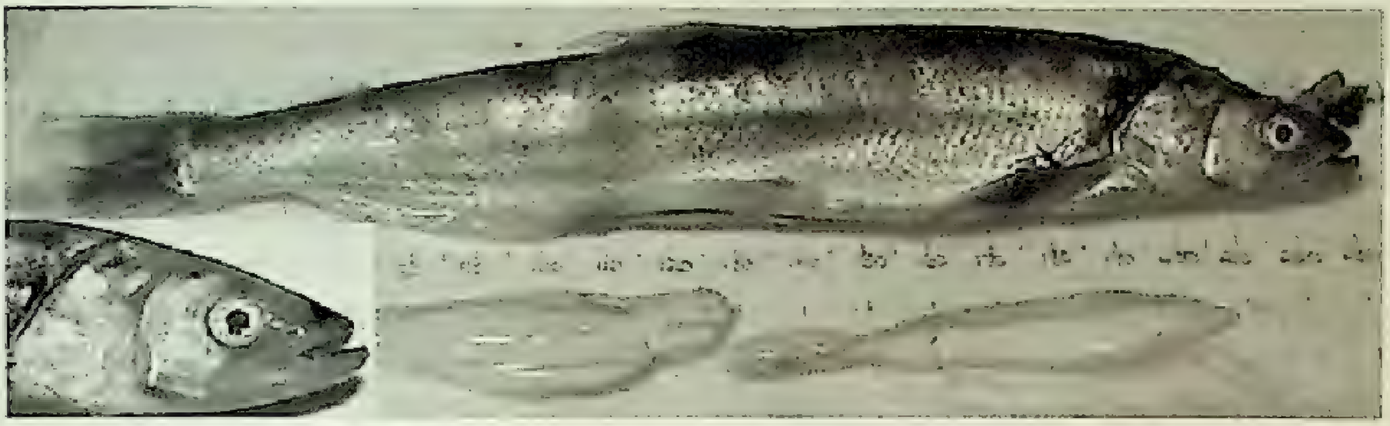

Figure 1. Eulachon collected at Knights Landing on 27 January 2006, showing the testes at an advanced stage of development. The inset shows the concentric striations on the operculum. Photos by M. Brown, CDFG.

Ageing with scales and otoliths yielded variable results. While circuli characteristic of cycloid scales were readily detectable in scales that were cleaned, dried, mounted between microscope slides, and viewed under a dissection microscope, there were no evident patterns associated with annulus formation. Thus, scales were not useful for ageing the eulachon. Otoliths were lightly ground and polished for viewing of microstructure as described by Titus et al. (2004). When viewed under a dissection microscope with the lateral surface facing upward, three major zones of translucence were apparent, including one near the otolith edge, that may have corresponded to three annuli, the third one having formed shortly before date of capture. Hay and McCarter[1] (2000), who provide a critical review of eulachon ageing, used comparative length-frequency distributions of eulachon in British Columbia to estimate age at time and location, in concert with otolith ageing. They determined that most spawning eulachon were age 3, ranging up to about 20 cm in length. This information is consistent with our results, although we note that there is a need for information on size and age at spawning for California stocks of eulachon.

The testes from our specimen were well-developed (Fig. 1) and had a composite wet weight of 3.7 g. The GSI was 6.6%, which was comparable to results for Stokell's smelt, *Stokellia anisodon* (Family Retropinnidae, southern hemisphere smelts), where spawning males had mean monthly GSIs up to 7.2% (Bonnett 1992). Male and female eulachon collected previously outside of their known spawning range by Odemar (1964) had undeveloped gonads, and were considerably smaller (average 143 mm TL) than spawning eulachon in Columbia River tributaries (average 170 mm TL, as cited in Odemar 1964), in British Columbia streams and rivers (average about 156 mm SL; Hay and McCarter[1] 2000), and in the present report (217 mm TL). Finally, the stomach of our

specimen was empty, which is consistent with information provided by Hay and McCarter[1] (2000) and Moyle (2002) who indicate that eulachon do not feed while in fresh water to spawn, and in fact have reduced dentition during this period.

Thus, given the information presented above, the eulachon captured at Knights Landing appeared to have migrated up the Sacramento River with the intent of spawning, where observed water temperature (9.5°C) was suitable for eulachon spawning, as reported by Moyle (2002). Yet, spawning runs of eulachon have not been reported in any stream south of the Mad River, including the Russian River (Odemar 1964, Moyle 2002). We also found no earlier historical evidence of eulachon occurrence in the Sacramento River system. When cataloguing fishes of the Sacramento and San Joaquin rivers, Rutter (1908) did not list the eulachon as a species found in this system. Eulachon were also not listed during a similar faunal survey conducted in the coastal streams of Oregon and northern California (Snyder 1908) where eulachon are known to exist. Eulachon could have been missed in these surveys because of the limited period that eulachon are present in fresh water (typically January through May as adults, and with larvae washing out to estuarine and marine waters shortly after hatching), and if sampling did not occur during the peak of the spawning run, which occurs during March and April in the Klamath River (Moyle 2002). However, this could not be assessed from these earlier studies because exact sampling dates along with locations were not reported.

In conclusion, we cannot ascertain exactly what conditions led this eulachon up the Sacramento River where it was eventually entrained in the rotary screw traps at Knights Landing, or if it was accompanied by other eulachon that may have found a seemingly suitable river for spawning. Future, if any, observations of this species in the Sacramento River system may help address these questions.

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